AN ANALYSIS OF MODELING SATELLITE DATA

IN AIR LAND COMBAT MODELS

THESIS

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Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Space Operations

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Preface

This study was initiated as the result of a conversation with Mr. Richard Porter. In our discussion of models, he mentioned the lack of satellite data in many combat models and yet felt this deficiency did not cause a problem in model validity. I challenged his feelings and set out to prove that small changes in combat models will have a significant impact on the results.

When I approached Major Dan Reyen with my ideas, he suggested I might be able to show this impact to a model through the use of a war game. This type of model became the focus of my study. Though it was initially thought that playing a game would simply provide entertainment, I quickly learned it was time consuming, thought provoking, and in many ways simply work.

I am indebted for the help provided with this study from many people. In particular, I wish to thank Major Dan Reyen for his guidance in combat modeling and the vast background information he provided. I also wish to thank Lt Col Bruce P. Christensen who patiently advised my work and became more than just a source of information, but became a great friend. Finally, to my wife Kelly and three children, Angell, Ty, and Kyle, thanks for putting up with all those long days and nights. Great News -- Daddy's coming home.

Tim G. Cordner

Table of Contents

List of Figures

AFIT/GSO/ENS/88D-5

Abstract

The purpose of this study was to examine the impact of satellite information on combat modeling. Modeling validity may be enhanced when greater detail is included in the model. The degree to which the model results may change by providing satellite information to, or deleting it from, the combatants in the model comprised the focus of this study.

A war game, entitled *The Falklands War* was used as the combat model. This game provided a series of results wherein the British forces were supplied satellite information. Additional play of the game removed this satellite information from the British forces and provided it to the Argentine forces. These two styles of play resulted in statistical data for analysis of the impact satellite information has on the results of this model.

The statistical analysis conducted on this model provided insufficient evidence suggesting the impact of satellite information on the model. Player variability and lack of sufficient data were determined to be the primary reason. However, from the data collected, little is observed which indicates playing satellite information in a board game, similarly to what has been done here, will produce the evidence needed to justify modifications to more

extensive and complex models. The requirement still exists to determine what impact satellite provided data will have on a model. Though it was hoped that an analysis of playing satellite information within a board game could provide such understanding, this research suggests otherwise.

Recommendations for further studies, involving war games as combat models, suggest limiting the human aspect found in the model. This may be accomplished by performing a similar study with only two participants involved in data collection.

AN ANALYSIS OF MODELING SATELLITE DATA IN AIR LAND COMBAT MODELS

I. Introduction

Modeling Background

From the beginning of the game of chess through the advances of the computer, mankind has been involved with simulating war. Simulation of combat has taken on many forms throughout history. Training camps, field exercises, and war games are but a few of the activities standing armies have embraced. Though activities of this nature are still used, the complexity of modern warfare has directed a new focus on the simulation of war.

Simulation is a means of replicating realism. To better understand the world around us, mankind has developed models. These models are used to simulate existing conditions or to predict outcome of possible events. An example of such a model is Newton's laws of physics wherein Sir Isaac Newton explains force, $F = ma$, as a product of mass and acceleration. Such a model has become readily accepted as approximating force as it occurs in nature. When an occurrence in nature becomes increasingly complex, the predictive ability of models tends to decrease. It is this level of complexity which divides objective models, such as Newton's model previously cited, from subjective models, such as those which try to explain how man will behave in a battlefield environment.

Current Modeling Issues

Models are continually being designed to help decision makers better understand how men and material operate during battle. Before a new weapon system is brought into the military inventory, the system is often tested by means of a model and judged, based on the output from the model. The results of such simulation can provide valuable aid in determining the continuation or cancellation of a potential weapon system. When considering the multi-billion dollar weapon systems being planned and developed, the importance of a realistic model in judging systems performance becomes obvious.

In a report to the Congress of the United States, the Comptroller General stated:

> Weapon systems costing hundreds of millions or billions of dollars, composition of future forces, and other defense planning and decision making often are justified in part, or supported, by quantitative studies. DOD estimates that the annual cost of such studies is about a quarter of a billion dollars. (13:cover page)

The quarter of a billion dollars being spent on studies of defense systems, as mentioned above, has prompted executive decision makers to request an improvement to model realism (22). "There are billions of dollars riding on the analysis game--we can't afford to be wrong. Tell the model 'owners' if their models are defecient!" (35). Improving realism is a function of including more and more of the relevant factors found in the system and including them to a greater level of detail. This added effort of increasing detail may or may not improve realism, but at least it tends to increase face validity. While more realistic models are the ultimate goal, an increase in complexity causes an increase in model development cost. The question then becomes determination of when the model is real enough to provide the information required for multi-million dollar decisions. A balance is needed between the cost of the system being studied and the cost of the study itself. This balance will determine the complexity of a model and the assumptions needed to make the model effective.

Problem Statement

Air Force Space Command (AFSPACECOM) has been tasked to incorporate the characteristics of major space systems into widely used land and naval combat models (22). Before this tasking is accomplished, a few questions should first be answered.

(1) How are space systems presently being modeled?

(2) Are present modeling techniques adequate?

(3) If changes are made, are the results worth the cost?

These questions will be addressed in this thesis through the study of one combat simulation and a statistical analysis of the results generated with and without a change to the simulation.

Objectives

Improving the validity of a model requires the model designer to more fully simulate reality. The task of showing model improvement can be accomplished by modifying an existing model to include finer detail of the phenomena one wishes to simulate. This type of modification will substantiate the validity and drive the model closer to reality. The only drawback to such an approach is the time and money such a tasking would require. For example, Seth Bonder of Vector Research Incorporated stated, "Many existing war games have taken four to eight years to develop ... I know of a war game which took six months to obtain one realization of ten hours of battle" (4:73). If modeling a single ten hour battle can require over six months of effort, the modification of such a model could easily require a similar amount of time (4:73). Though such an effort may drive the model closer to reality and possibly substantiate the validity of the model; until the model is modified, verified, validated, and results analyzed, the question still remains unanswered as to model improvement.

To understand the problems associated with demonstrating model improvement, several questions need answering. For example:

1. How are war gaming models developed?
2. How has war strategy been modeled?
3. What are the different models used to simulate combat?
4. How can detail be added to existing models?
5. What impact on model realism will occur with the modification of existing parameters?

These are but a few of the questions which arise when discussion centers on changes to combat simulation. Though each of these questions are important and necessary to fully understand combat models, this thesis will ignore the design, development, and applications of models and focus on the effects generated when one specific combat simulation is modified.

A model can be considered an input/output transformation device. If you change the input, the output will change. If you change the model, the output will change. If both the input and the model are changed, the output may or may not change depending on whether the changes are compensating. When a model is developed, it is assumed the results reflect reality "good enough". If you alter the model, the question becomes, is this new model better at reflecting reality. If so, is the change worth the cost and effort of the model alteration?

When working with manual war games, the model structure is defined by the rules which govern the play of the game. The input data is determined by the participants. By altering the rules and allowing different players to participate, the results may vary from unmodified games due to a change in both the model and the input data.

This study will consider the simulation of space assets in a board game. By focusing on a simple board game and altering the rules to reflect space assets, some degree of change is anticipated in the model results. If a significant change can be shown at this level of modeling, modifying more extensive and complex models will be indicated.

Scope

The scope of this research will center on the final question posed above; what impact on model realism will occur with modification to existing model parameters and processes. To fully address this issue, a review of what space offers and how it is provided will be discussed. A look at how space assets are presently being modeled along with an understanding of how combat modeling is performed will set the stage for the statistical analysis of a modified board game. The review of combat modeling will show the correlation between a simple board game used in this study and a theater level computer-generated combat model. It is this correlation which indicates that the results achieved from a game would likely be achieved in a more complex combat model.

Research Question

The questions this research addresses are:

> What impact will space related modifications to existing models have on the realism of the original model and are such modifications worth the effort?

By answering these questions, the need for modifications to existing models may be better understood and more easily justified.

Terms Explained

The following terms are used extensively throughout combat modeling.

System

We define a system to be a collection of entities or components which interact with each other and with the environment in an attempt to achieve some goal. (14:1-1)

Model

A _model_ of a real system is a representation of some of the components of the system and of some of their actions and interrelationships which is useful for describing or predicting the behavior of the system (within a reasonable range of inputs). (14:1-2)

Game

A _game_ is a model 'opened up' to allow human interaction. Rather than logic code for decision making, human players perform the decision making (24:155-156). Uses of gaming are as an organizing device to pull things together, as a training and indoctrination technique, and, finally, as an analytic tool by which different concepts, different pieces of hardware, or different military plans can be investigated in a two-sided confrontation. (37:266)

Symbolic Models

A _symbolic model_ is a model which represents a real system using mathematical equations or computer programs. (14:1-3) A descriptive model using words or diagrams is also considered a symbolic model. (17:14-15)

State Variables or Attributes

Symbolic models use mathematical variables to describe the state of the system being modelled. These variables are called the _state variables_ or _attributes_ of the system. (14:1-3)

Dynamic versus Static

A model is called a _dynamic_ model if it explicitly represents the passage of time. A _static_ model, on the other hand, refers to only a single instant in time. (14:1-5)

Continuous versus Discrete

A model is called a _discrete_ model if the state variable values change at only a countable number of instants in time. In a _continuous_ model, state variables can change at any time. (14:1-5)

Deterministic versus Stochastic

If a model contains no probabilities or random effects, then it is called a deterministic model. Stochastic models are those that incorporate uncertain occurrences using probability distributions over the sample space of possible outcomes. (14:1-6)

High Resolution

A high resolution combat model is one which includes the detailed interactions of individual combatants or weapon systems. Interactions among combatants are resolved at the one-on-one engagement level -- often computing separately the results of each individual shot fired in the battle. (14:1-6,7)

Verification

Verification is determining whether a simulation model performs as intended, i.e., debugging the computer program. (18:333-334)

Validation

Validation is determining whether a simulation model (as opposed to the computer program) is an accurate representation of the real-world system under study. (18:334)

Materials used

Data collected for this thesis was generated from the board game *The Falklands War -- Naval Conflict in the Missile Age*. This game was developed and copyrighted by Close Simulations, Northbrook, Illinois 60062, in 1982. The game is a two sided, interactive, stochastic simulation of the conflict which took place between the British forces and the Argentine forces over control of the Falkland islands.

Conclusion

This chapter introduced the world of combat modeling and some of the problems associated with it. The questions of model realism, cost, and trade offs between the two were presented along with some of the concerns found in the modeling community. It is these concerns which will be addressed in the chapters that follow. Chapter II is a review of the literature pertinent to space assets and war gaming. Chapter III outlines the methods used to test for the significance of satellite information in combat modeling. Chapter IV presents the results of testing with conclusions and recommendations found in Chapter V.

II. Literature Review

If you take a flat map
And move wooden blocks upon it strategically,
The thing looks well, the blocks behave as they should.
The science of war is moving live men like blocks.
And getting the blocks into place at a fixed moment.
But it takes time to mold your men into blocks
And flat maps turn into country where creeks and gullies
Hamper your wooden squares. They stick in the brush,
They are tired and rest, they straggle after ripe blackberries,
And you cannot lift them up on your hand and move them.
-A string of blocks curling smoothly around the left
Of another string of blocks and crunching it up-
It is all so clear in the maps, so clear in the mind,
But the orders are slow, the men in the blocks are slow
To move, when they start they take too long on the way-
The General loses his stars and the block-men die
In unstrategic defiance of martial law
Because still used to being men, not block parts.

-Stephen Vincent Benét (27:xi)

The Advantages of Space

Before a model can include space assets, some idea of the capabilities of space assets is needed. Mankind has been involved with space platforms since the late 1950's. In that time, the applications of space based platforms have grown. Of particular interest to combat modeling is the military applications of space.

> Beyond communications, military applications of satellites include reconnaissance, navigation, meteorology, and tracking. Research is being conducted in antisatellite weaponry, encryption systems, undersea satellite communications, and battle stations in space. (2:587)

These general areas of military concern are available from space based systems. But to include them into the model requires an understanding of how space assets works and what kind of data is received from space.

Using Space Platforms

Using a platform high above the battlefield for reconnaissance began in the days of the civil war with the introduction of the hot air balloon. This look down approach to gathering information is a simple explanation of what satellites do. Satellites are orbiting platforms which contain sensors used to collect physical data relating to an object or ground feature. This is referred to as remote sensing. Figure 1 depicts the processing flow of remotely sensed data. In the past, remotely sensed data were derived primarily from the visible portion of the electromagnetic spectrum using the eyes or a camera. Today, sensing takes place from the ultra-violet, through the visible, through the infrared, and into the microwave wavelengths of the spectral regions (20:71-72). When the man in the hot air balloon spotted something of interest, he would call or come down out of the balloon and relay the information. The processing of information from satellites is considerably different.

The flow of information from space is not as simple as from a hot air balloon and requires a lot of support both in space and on the ground before the information requested can be received. The acquisition of the object requires precise flying of the satellite followed with detection of radiation energy and conversion of this energy into digitized pulses

Remotely Sensed Data	Imagery in the ultra-violet, visible, infrared, and microwave spectral regions.
IMAGE ACQUISITION	Observations with image scanners, cameras, and radar sensors.
IMAGE TRANSMISSION	Image data transmission to satellite relay and ground receiving systems.
IMAGE PREPROCESSING	Image calibration, formation, radiometric and geometric corrections.
IMAGE ENHANCEMENT	Image enhancement for manual interpretation by visual means.
INFORMATION EXTRACTION	Computer processing of sensor data for conversion into info.
PHENOMENON MODELING	Mathematical modeling of phenomenon of interest for prediction.

Interpretation, Analysis, Inventorying, Surveying, Prediction, Understanding.

Figure 1. Processing flow of remotely sensed data (20:72)

for transmission. The transmission of the data involves data links around the world. The image preprocessing and enhancement uses massive computer memory to convert the pulsed data into information products for distribution. It then becomes the responsibility of the user to interpret the information correctly (20:71-74).

The sensors aboard the satellites have the same advantage as the man in the balloon; however, what the sensor sees is a function of the orbit in which the satellite is placed. The orbits common to satellites are either circular or elliptical. These two types of orbits cause the satellite to rotate around the earth with the focus of the orbit located at the center of the earth. For the circular orbit, this means the satellite will maintain the same altitude above the surface of the earth and travel at a constant speed over the ground surface. The elliptical orbit is not quit as simple. The altitude of the satellite and the speed at which it travels over the ground will both vary. In both cases, the actual terrain covered by the satellite will vary due to the rotation of the earth and the altitude of the satellite above the earth. Considering all these factors, the actual ground trace which the satellite covers is a function of the parameters of the orbit in which the satellite is placed (3:21-73).

In order for a satellite to view an object of interest on the ground, the sensor must be positioned over the subject. This requires planning for orbits which will permit overflying areas of interest. In order to view a time dependent subject, i.e., only visible between 9:00 and 10:00 A.M., the satellite will need to overfly the subject within a window of time where the sensor can view the subject. If only one satellite is available, the sensing of ground information is severely limited to the orbit parameters of the satellite. Though satellite orbits can be changed to permit revisits to the same location on the earth in a timely fashion, such changes are costly. The needed fuel to make such a change requires a large portion of the reserve fuel aboard the satellite. When all the reserve fuel is depleted, the satellite is considered dead and no longer useful.

Satellites provide information. This information comes in the form of audio communications or visual displays. For military applications, both are important. The audio portion of satellite information provides rapid response and command and control of forces throughout the world. The visual displays provide weather as well as intelligence information. The use of this kind of information has become critical in combat engagements and is necessary for the operations of many modern weapon systems (20:187-226). Because this information is so critical to modern warfare, the representation of satellite information in combat models is critical. Before discussing how satellite information is presently being modeled, a look at modeling in general will help explain the difficulty in simulating reality.

Modeling Tree

When talking about a model, the images one gets will vary. To some, a model is associated with clothing, fashion design, or mail order catalogs. To others, a model may be a small replica of an airplane, a battleship, or car. Still others think of models as computer programs, equations, or numbers. All of these images are models. In a Rand report for the United States Air Force, a model is defined as "an analog of reality" of which questions can be asked and answers received giving insight into the real world the model corresponds (32:212). From this definition, one can see where each picture described above can be called a model. For the purposes of this study, a more specific picture of where war games fall into the realm of models must be determined.

Models can be classified into one of three descriptive types. Dr. Francis B. Kapper terms these three model types as iconic, analog, or symbolic (17:14).

Iconic models are look alike objects. To the individual who called his miniature airplane a model, this depiction of reality is an iconic model. By subjecting this model to wind tunnel tests, an idea of how the real airplane may perform can be inferred (25:7).

An analog model is an attempt to represent a physical relationship found in nature with numbers. "For example, a slide rule replaces quantities by distances proportionate to their logarithms" (17:14).

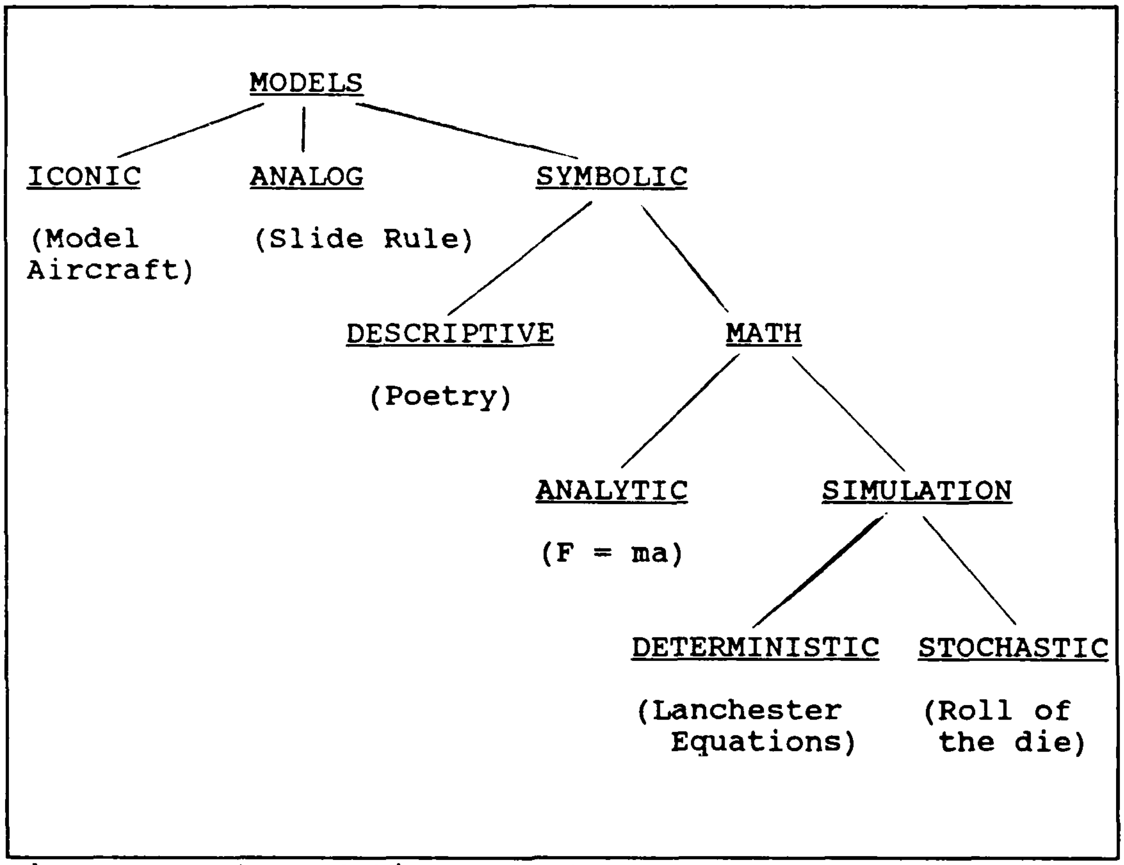

Figure 2. The Modeling Tree (29)

A third model type is a symbolic model. This is an attempt to represent real world properties with numbers, letters, or other symbols. This type of model can be further described as either a descriptive or mathematic model. Figure 2 shows there relationships. The descriptive model uses words or diagrams to express the real world. The typical organizational flow chart is an example of a descriptive symbolic model. Mathematical models are more in tune with the thinking of operational research. These models express realism with logic or quantitative relationships. They can be static or dynamic in their representation, and are often thought of as either analytical models or simulation models (17:14-15). The analytical model seeks for an exact number. This point estimate of reality has its place in the hierarchy of models and will be discussed later. The simulation model is a series of "... models that may be used to converge on solutions to very complex problems involving uncertainty (probabilistic occurrence) and risk" (17:15). These models can be either deterministic, which include Lanchester equations found in war models, or stochastic, where random number generators are used to determine the outcome. Uncertainty and risk are found in war and consequently combat models are often considered simulation models. Figure 2 depicts the various types of models discussed thus far and how they fall within the modeling tree.

Simulation Math Models

Some of the techniques used to treat command decision making are found in simulation math models and include:

> ...1) human participation; 2) game-theoretic and related techniques; 3) optimization and related techniques; 4) mechanical-statistical and related techniques; 5) controlled experimentation; and 6) expert systems and related techniques (which we also call knowledge-based techniques). (11:766)

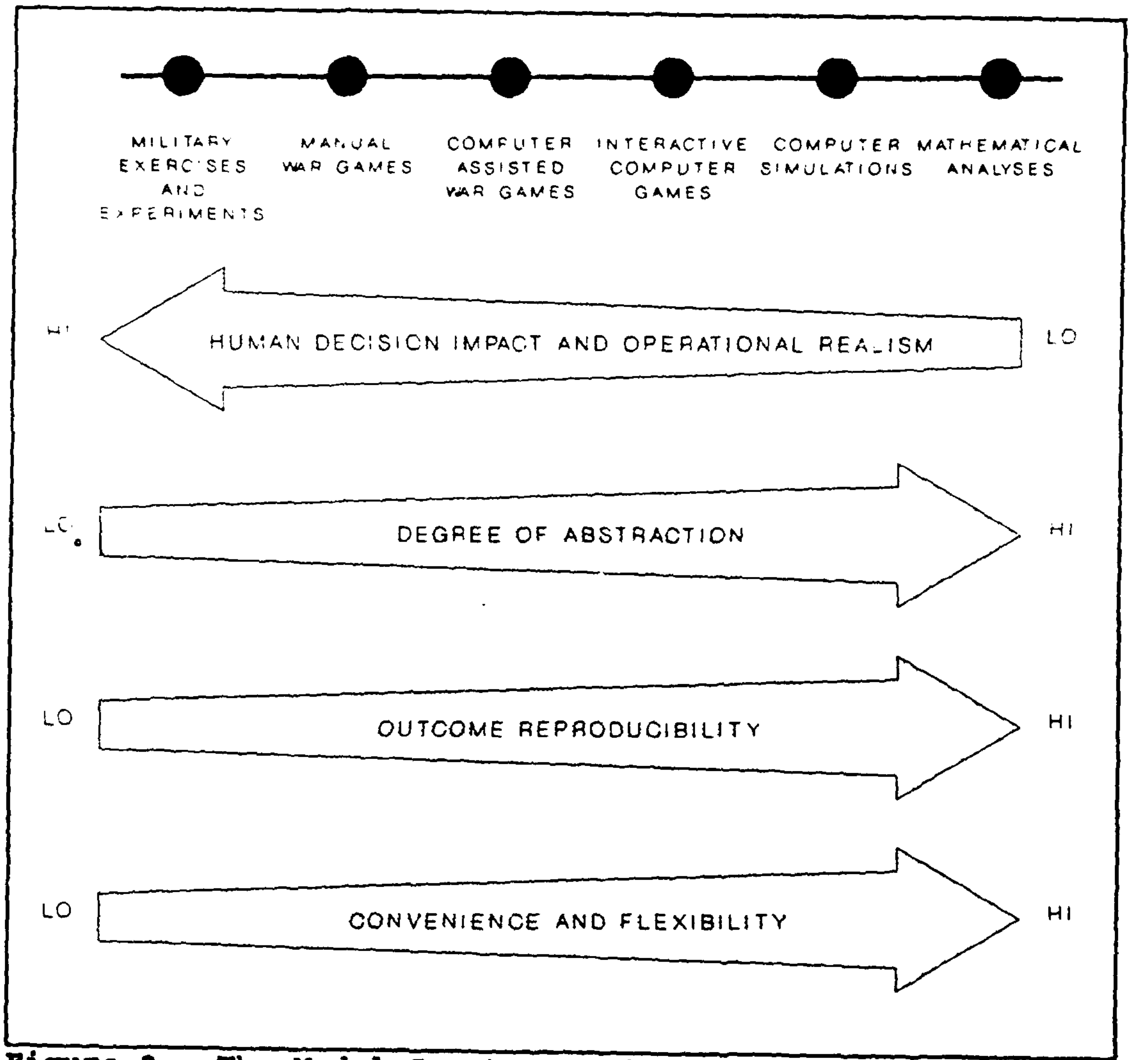

Figure 3. The Model Spectrum and Characteristic Trends (15:10)

These six techniques lend themselves well to the trends of modeling found in Figure 3. Human participation techniques include military exercises, experiments, manual war games, interactive war games, and computer assisted war games. Further to the right in Figure 3, the expert systems relate very well with mathematical analyses and computer simulations. The figure then indicates a degree of operational realism, degree of abstraction, level of outcome reproducibility, and convenience and flexibility when working with these modeling techniques. Though this figure indicates a distinct difference between models, Mr. Farrell has attempted to create an overlap between the modeling techniques. While working at Vector Research, Incorporated, Farrell, along with Dr. Seth Bonder, has been experimenting with game theory and the use of games to "provide a base for the development of rule-based (knowledge-based) expert systems to simulate command decisions" (11:771). The data generated by military exercises and manual war games represent a high degree of operational realism and human decision impact. This data, produced by the games, can be used to "...derive rule-based (knowledge-based) expert systems which will simulate the decisionmaking behavior of the gamers. These expert systems will then be incorporated into the VECTOR-3 model for use in more extensive analysis of variations in airlifter characteristics" (11:771). This interaction between human involvement found in manual war games with computer run expert systems indicates one way Farrell and Bonder are trying to better capture the phenomena of human decision making in their model to improve its realism.

Difficulties in Modeling Combat

Whenever someone is interested in simulating a complex system, some understanding of the pertinent factors of the system is needed. "Particularly important is the understanding of which interactions can be ignored to simplify computation and which must be retained to stay fairly close to the real world" (34:36).

Combat models consider two aspects of war: the physical processes, such as weapons effects, and the man behavioral processes including decision making. Matching power and kill rate has been better understood and received greater attention in combat modeling for some time, but the human involvement of command decision making has been more difficult to model (11:766). Whereas, command decision making is now beginning to receive some attention, that which was thought to be understood is now being questioned. The attrition rate in many models appears to be questionable and has drawn criticism from the Government Accounting Office:

> The choice of attrition profoundly affects the results of cost-effectiveness analyses--and consequently Defense Decision. You would expect, therefore, that the models would agree on the basic form of attrition for a specific real world process. If that is what you expect, you are in for a grievous disappointment. (13:70)

Weapons effects, attrition rates, and decision making are not the only shortcomings. According to Robert Farrell, human participation (gaming) or man-in-the-loop techniques suffer from 1) variability introduced by gamers, 2) the expense of the game, and 3) typical use of unacceptably over-simple assessment methods to represent the combat. The lack of consideration for imperfect decision making seems seldom dealt with (11:766-767). Because of man's imperfections, his involvement in war games will increase the difficulty in assessing outcome results. In an address to the U. S. Army Operations Research Symposium, Dr. Seth Bonder expressed similar feelings.

> A war game is a model which is, in a sense, a step removed from the reality of a field experiment or a field exercise wherein only teams of players representing the commanding officers and their staffs are included. Since decisions are made by humans, it is not unreasonable to expect a high output variance if different decision makers were used; however, the long operation time usually precludes more than one realization of the process. It is my personal view that this type of model is not a feasible mechanism for analyzing a broad spectrum of system alternatives in a responsive manner to meet planning cycle requirements. Experience has shown, however, that they are diagnostic in the sense that they reveal problems that need to be resolved with future systems, and are viable mechanisms for training decision makers. (4:73-74)

Rule based systems find a different set of difficulties. They include 1) deciding which concepts of operations become more or less likely in a given situation, 2) restricting the number of alternative concepts to a manageable size, and 3) forcing the combat models involved to execute the concepts of operations as designed (11:768). Mechanical-statistical rules have been

> ...the method of choice for most low-level command decisions in simulation. They do not, however, make them satisfactory at the high level. No adequate treatment of these high-level command problems exists in terms of simple rules. (11:768)

There are those who contend that many decisions are being made based on the outputs of computer models and simulations of combat which are recognized to be unrealistic. Dupuy argues that too little history is being applied to present modeling techniques. He references ten operations research analysts who claim perceived analysis methodology weaknesses include uses of overly complex, opaque, tools, too little use of history, and model anarchy (9:16).

To summarize the difficulties found in modeling combat, the presented literature suggests shortcomings in five areas: (1) simulation of human decision making, (2) the attrition rates used in weapon degradation cannot be considered constant over time, (3) models involving human interaction increase variability in results, are expensive, and over-simplify many aspects, (4) rule-based models restrict alternatives, and (5) an inherent failure in model development to include the past. These five areas are some of the concerns found in modeling combat.

Model Evaluation

> Fishman and Kiviat divide the process of evaluation into three categories: (1) Verification to insure that the model behaves as the experimenter intends; (2) Validation to test the agreement between the behavior of the model and the real system; and (3) Problem analysis which deals with the analysis and interpretation of the data generated by the experiments. (31:293)

The validation step is often the most difficult and time consuming portion of model development. Though some modelers mistakenly wait until the model is complete to accomplish validation, continual verification and validation are recommended. The methods of validation are varied but many agree on the following approaches.

Face value is a popular method of validation. Mechanical rules used in many models must be approved prior to implementation and a common method of approving rules is through face value. A panel of experts, with background and experiences of combat, is pooled to make up an outline of how the rules should be developed. Though these rules may not be in total agreement with any one expert, it captures or approximates the most agreed upon features of the combat situation in question. This synopsis of combat, formed in a rule book, becomes a means of validation (11:768).

"One of the most obvious approaches to helping validate a model of an existing system would be to compare the outputs of the real world system and the model, using (if possible) identical inputs" (31:294). Though this process is never possible, it is attempted to some degree. Weiner sums it up in his article, *Gaming*, when he states:

> The validity of a war game does not ordinarily lie in the accuracy with which the mathematical computations or the arithmetic is done, but rather in the extent to which the sides can be faithfully represented and the rules be designed to bear some relationship to real operations. (37:267)

Validation is an integral part of a system analysis. Though the analysis of output data is often the focal point of any study, verifying and validating the modeling process as well as analysis of input data share equal importance.

Military Games and Simulations

Military exercises and manual war games are being used to develop the input data to computer simulations and mathematical analyses as well as aiding decision makers in justifying choices. Through a contract with Alphatec, Inc. of Boston, MA., the Air Force Armstrong Medical Research Laboratory is using estimations, decisions, and game results to develop normative and descriptive models. These models are attempts at simulating the human thought process as it relates to combat (21). Even though these models are considered research models, it is hoped that one day this information can be incorporated into application models.

A witness to the games played in the Pentagon where possible war scenarios are simulated on a regular basis has stated:

> Games give policymakers a cheap and quiet way to go to war for the mundane purposes of planning budgets, for tinkering with the size of Army divisions and Navy fleets, and for putting nonexistent weapons and outlandish tactics onto mythical battlefields. (1:6)

This same author tells of the high level "games" played in the White House during President Johnson's term in office. Having read the transcripts of these games found in President Johnson's library, he commented:

> The dialogue in the games showed again and again an arrogant, unquestioning belief in signaling; a reliance on gaming-table analysis over GIs-in-jungles reality; and an incredible faith in the usefulness of strategy worked out against a "Red Team" that consisted of American military officers and civilians playacting Viet Cong and North Vietnamese leaders. Vietnam-era gaming, which attracted the rational war planners who first appeared in the McNamara Pentagon of the 1960s, has continued to influence policymaking in every presidential administration since. (1:10)

Present day war gaming results are finding their way into the current SALT talks (1:25). In his book, Pentagon Games, Mr. Prados tells of the Studies Analysis and Gaming Agency (SAGA, recently renamed Strategic Analysis Division) found in the Pentagon. This division is responsible for military gaming and as such "...manages the externally contracted gaming program, keeps track of all simulations used in the military, performs systems analysis studies for the Chiefs, and conducts games of its own among the armed services and civilian leadership" (27:8). He goes on to point out the millions of dollars each year being spent on military war games. He contends that with over 800 professional wargamers, contracts to "think tanks", and each services independent studies, as much as $100 million annually is allocated to games throughout the Department of Defense (27:8-9).

War Games and Modeling

Games are a subset of models and appear under the simulation branch of the modeling tree. Gaming has shed light on both the payoffs from different strategies and the capability of the enemy to alter strategies (11:767). Games have been used to assess tactics, train participants, and educate potential combatants in the nature of war fighting. These benefits prompted the USAF to contract Close Simulations to develop and produce a board game called *FEBA* (23). In introducing this game, Lt Col Robert C. Ehrhart, USAF Project Warrior Coordinator, stated,

> "*FEBA*" is a special training tool which can significantly enhance participants' understanding of the nature of air-to-ground operations, performance capabilities and tactics, and situational awareness. "*FEBA*" can provide training for operational specialties in addition to aircrew, including weapons controllers and intelligence personnel. It is unclassified, but provides aircraft and air defense capabilities analogous to their real world counterparts. (10)

Though a battle has many aspects to it, a game can take a small portion of the overall environment and attempt to gain some insights into combat success and failure. An example of a small portion of combat is a tank dual.

> By considering a simple situation where two combatants are in isolation, it is possible to examine a single element of complex battle. In this manner, the probable outcome of such a dual may be estimated, and a positive step in the formulation of an analytic model of a more complex engagement may be established. (36:545)

War games are found in many forms. They include field exercises using real troops in mock combat, map exercises with a group of people moving small blocks around a sand table or map, and simple parlor games with two people using pencil and paper to play out games like *BATTLESHIP*. War games typically have "sides" which often are represented by blue and red forces. To be an effective war game, it should have a purpose. Individual objectives, which each side attempts to meet, often make up the purpose. Moreover, all games have rules. With these simple guidelines, war games are developed (37:266-267).

The RAND Corporation has taken war games far beyond the simple parlor arena of fun and applied their use to strategic decision making. Examples of games developed by RAND include Strategic Air War games (STRAW), Strategy-and-Force-Evaluation game (SAFE), Cold War game (COW), and a map exercise for limited war called SIERRA (37:267).

War games are considered a vital part of the modeling community. Mr. Wilbur Payne has included war games under the titles of training games and research games. His description of the hierarchy of combined arms combat models as the interactions of modeling techniques is shown in Figure 4. To the far right, the figure depicts analytic models. These are the point estimates of reality. The

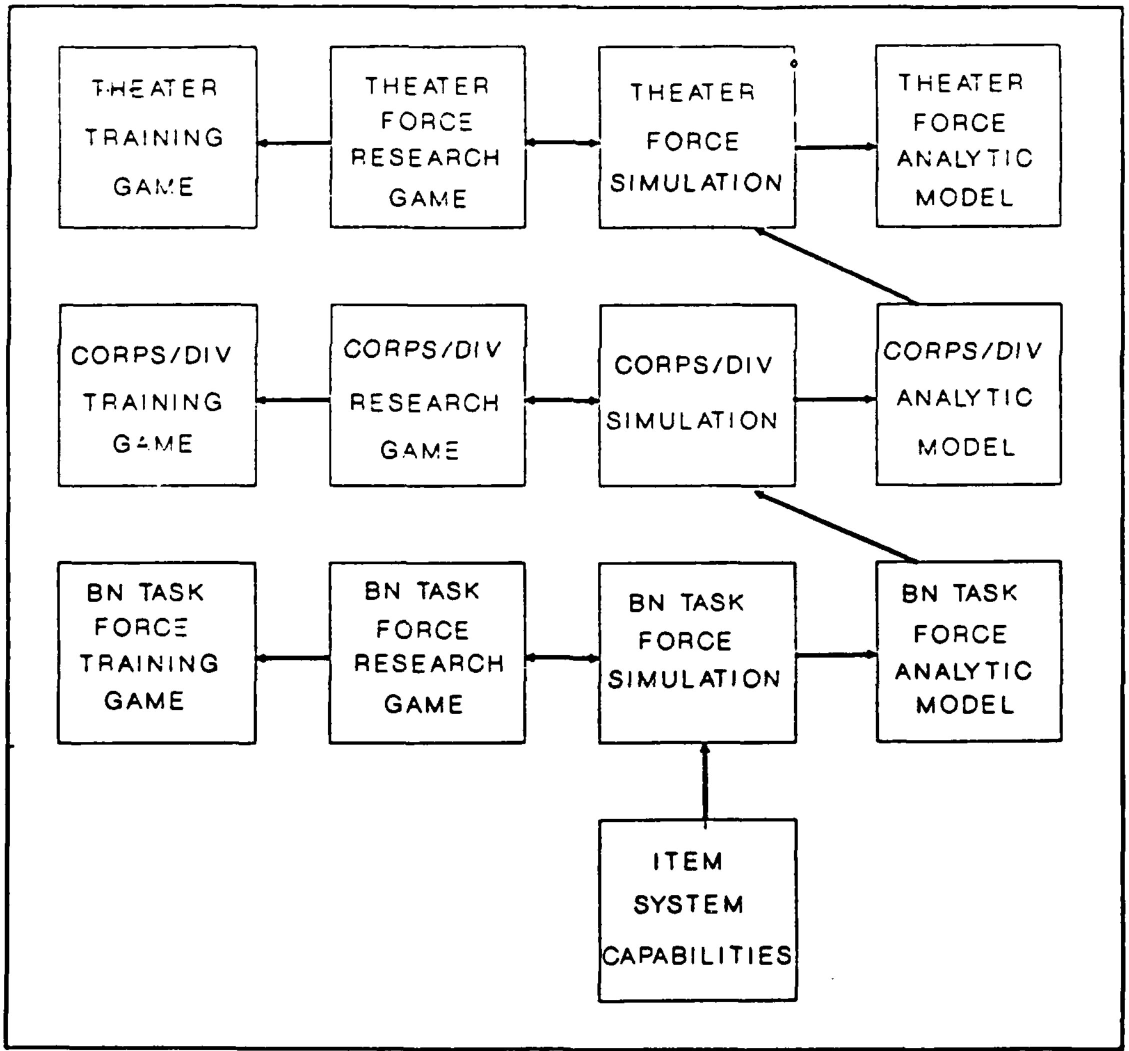

Figure 4. The Hierarchy of Combined Arms Combat Models (24:154)

intent of these models is to find an exact answer which can provide data to other models. The diagonal lines show this transfer of data from analytic models to simulations. This transfer occurs across an aggregated level. For example, the analytic results from a model depicting a battalion will be integrated into a corp or division level simulation. The horizontal interaction shows how the results from one model can be used as input data for models of the same aggregate level (24:153-155). Here, the results from a battalion task force research game can be used as input data to battalion task force training games or simulations.

> Lateral and even diagonal movement is also possible. Ideas for improvement or the identification of problems that need attention can originate anywhere in the hierarchy, including from training games. Furthermore, the proper remedy for a problem identified somewhere in the hierarchy is as likely to be found through tactical or organizational changes as through new material development. (24:155)

Board games are considered a combination of research games and training games. The playing pieces represent the actual force structure of opposing units. These are manipulated by players simulating the role of commander. It is through this interaction of player and pieces that both training and research can be accomplished (4:73-74).

Present Techniques in Modeling Space Assets

After a look at what space has to offer, along with a review of modeling and how it is done, the next step is concerned with how space assets are presently being modeled. The US Army Training and Doctrine Command (TRADOC) publishes *The Inventory of TRADOC Models*, which contains 33 separate models presently used throughout DOD. The computer assisted models cover combat simulations of force-on-force, logistics, training support, and functional areas other than logistics. A look at the force-on-force theater level models reveals a common starting point. The information available from space assets are pre-determined and are considered input data to the model. The weather, communications structure, and positioning of both friend and foe are assumed as known information before the model is run. Some of this known data is generated by other models. For example, one model, titled *ASAS Performance Assessment Model*, collects data gathered about the threat as input data and produces a description of threat as its output. It does not consider attrition between opponents and can be used only as a link between an information gathering model such as ENSIM and a combat model such as VECTOR-2 (7).

No computer assisted combat model could be found which simulates receiving intelligence reports, weather reports, or positioning information periodically from space, similarly to what would actually occur. The assumptions were made that space would always provide the information and consequently, the input data would simply reflect this assumption. Though space assets can be considered reliable, they cannot provide continuous information. The data from space which relates to weather and intelligence is but a snap shot in time. As time is played in the model, this information becomes dated and unrealistic.

In games, the modeling of space information is somewhat different. For example, in the war game *The Campaign for North Africa*, weather is simulated by the role of a die. At the beginning of each turn, the die is rolled and the weather determined for the remainder of that turn. This assumes the weather will not vary during the time period which encompasses one turn. A turn consists of a two day period (33). Intelligence is simulated through movement. If one opponent is required to move first and reveal his move, this gives the second opponent the intelligence information of where the enemy is positioned and how he can then move to counter that position (6). Some games, like *Battleship*, eliminate the advantage of intelligence by requiring both players to position their forces simultaneously. This type of game neglects to simulate satellite information.

Possible Methods for Simulating Space Assets

Current combat modeling techniques rely heavily on computers. The speed at which a computer can analyze a complex collection of data allows a greater volume of data to be considered. The only drawbacks to most computer run simulations are the vast amount of set up time needed before the simulations can be performed and the volume of data generated which takes time to interpret (7). If space assets are to be included in combat models, computer code will need to be generated which considers the following:

1. What type of information from space is required?
2. Which satellites can provide this information?
3. What kind of network supports this satellite and how is the information routed through the network?
4. What are the orbital parameters of the satellite?
5. How often can the satellite overfly the area of concern?
6. Can the satellite be flown or moved to receive information from an alternate source?
7. How long can the satellite loiter over the battlefield?
8. How well can the information received from the satellite be correctly interpreted?

These are but a few of the questions which must be answered to correctly simulate satellites. Including satellite information in an existing combat model could be accomplished by adding a routine to the computer code which simulates the satellites of interest. This code could include the flight characteristics of the satellite, the processing of satellite information, and the interpretation of that information. This data could then be included in the combat simulation and updated throughout the simulation much the same as a real satellite system would. But before all the needed work is performed to write this code and integrate it into the existing model, the ultimate question must be answered, is it worth it?

Estimated Costs of Modification

The costs associated with computer run combat simulations are high. As was mentioned earlier, millions of dollars are spent annually supporting war games. One such computer simulation of force-on-force theater level conflict requires only ten minutes of computer time. However, before this run is made, two man-months of preparation are required to set up the model and one man-month is required to analyze the output (7). One modeler, working for the Department of the Army on the AirLand combat model Vector-In-Commander (VIC), estimates a minimum of one man-year just to code the simulation of satellite assets. This does not include verifying the results or integrating the code with an existing model. Further, he feels the information presently being simulated through data bases provides adequate results for the purpose of the simulation. Though the modeling community has been tasked to incorporate major space systems into combat models, the modelers feel the additional cost to upgrade existing models may not warrant what small benefit could be derived (26).

The time and money necessary to change a computer run combat simulation to include satellite assets warrants a study aimed at determining the benefit from such a modification. This thesis is such a study and attempts to determine what impact satellite information has on modeling combat. It is believed that if the information which satellites provide to a model can produce a significant change in model results, then the means of supplying this information to the model, through satellite asset simulation, will also produce a significant change.

This study considers intelligence as the information provided by the satellite. Intelligence is played in a board game through the movement phase of the simulation. The player which has the satellite information is given the advantage. He is permitted to see where his opponent has positioned his forces before he must commit his own.

The game selected to test this hypothesis is *The Falklands War*. During the battle between Argentine and Great Britain, the British had access to satellite coverage over the Falklands. This permitted the British to "see" where the Argentine forces were deployed and at what strengths (12:80-85). Determining what impact satellite information, such as intelligence, has on a model's results will help determine if modifying existing models to simulate access to this information is cost effective.

Summary

Military modeling of war is an attempt to capture a very abstract and highly variable human interactive situation. The devices used to represent warfare include parlor games, computer programs, as well as mock battles involving live participants. Simulation models, including board games and computer programs, attempt to replicate the uncertainty found in war. With increased emphasis on satellite capabilities, the impact satellites have on the battlefield require understanding. Some feel this understanding can be achieved by upgrading existing models to show satellite assets. Because the cost to accomplish such a request is extreme, a study of a simple board game will be performed to demonstrate the advantage satellite information has on combat modeling.

III. Methodology

Introduction

The research presented in this thesis was accomplished in four parts. These parts include a background study, design of the experiment, data collection and analysis, and finally, recommendations. This chapter describes the approach taken in each area.

Background Study

Before any problem can be tackled, a complete understanding of the environment is needed. A literature review of modeling and satellite information was performed. The review is contained in the previous chapter and presents the broad aspects of satellites and what they offer combat models. The review includes a discussion on military modeling and war gaming as it relates to combat modeling.

Design of the Experiment

Designing an experiment involves identifying the factors of interest, determining an appropriate means for measuring and evaluating these factors, identifying the test statistics, and determining the decision rule. Once this is accomplished, the next step is obtaining a sample, computing the sample statistic, making a decision based on the outcome of the sample statistic and finally stating the knowledge or value claims as a result of the experiment (28). Before any of this could be accomplished, the model to be tested was identified.

Model Description. To determine what impact input data has on the results of a model, a board game was chosen as the representative model. This game, entitled *The Falklands War*, simulates the combat which took place between British and Argentine forces in an attempt to control the Falkland islands. This game was chosen because of its simulation of a recent conflict in which satellite information (SI) played a significant role (12:80). A more detailed description of the game can be found in Appendix B. The game was designed giving an advantage to the British player by allowing this player to move after the Argentine player has committed his forces. The rules governing movement in this model simulate intelligence information. This type of information would likely come from satellites.

In the case of the Falklands war, the British forces were supplied SI which aided their intelligence gathering (12:80-85). This gave the British forces the advantage of deploying their forces to meet the foreseen strength of the Argentines. Had the British not been supplied with this information, the results may have been different.

There are those who claim both sides would have access to SI in times of conflict and therefore the movement phase of this game is unrealistic. This may be the case, however, it cannot always be guaranteed, nor was it the case in the actual conflict between these two countries. For the purposes of this study, it is assumed one side at a time is supplied with such information. This assumption provided a means to determine the impact satellite information has on model results. By holding everything else in the model constant, the impact of decision making with improved information can be measured.

Model Participants. The game required two players. The players selected for this research were not experienced in war games nor had they any military modeling background. The group consisted of Air Force aircrew members experienced in military airlift support operations. The actual pairing of participants, dates of play and game results are found in Appendix A. Though not a focal point for the research, the decision making process of the players involved will be noted later in Chapter V.

Expected Results. As with most games, the results provide the participants with a victor. In *The Falklands War*, the awarding of points is determined by assets defeated and ground controlled. For the purposes of this study, the victory tally considers the losses of ships, aircraft, and troops for each side. These losses are ultimately summed to determine the total victory points each player receives. The data collected consisted of the total victory points each player received at the end of the game as well as the fighting capability lost through the attrition of ships, aircraft, and troops. A record was maintained of the players and the role they played. This information provided the needed data for statistical analysis.

Factors of Interest. The purpose of this experiment was to determine what impact SI has on the results of the game. It is believed that if a significant change in model results is due to the information provided by satellites, then a significant change in results will occur as a function of how that information is fed into the model. If no significant change is found as a result of the information, other dominating factors in the model govern model results.

The measure of each players' effectiveness in defeating his opponent is determined through a tally of points for destroying or capturing enemy assets. Because the only measure of simulation output in this game is found in the loss of war fighting capability, this became the factor available for statistical analysis. The experiment considers the significant difference in lost assets to each opponent when playing with and without SI.

Identifying The Needed Test. As discussed previously in the introduction, output to a model can vary by altering input data, changing the model, or both. The first desired outcome of this experiment was to observe results after a change in the model. This required using the same two players in a series of games. It was believed that by considering only two players' results, the input data would remain constant. This eliminates the learning experience and "gaming" of the game each new players contributes. The focus question became, is there a change in one opponents' losses when playing with or without SI. Two possible conditions exist which could be explored. These conditions were expressed in a null and alternative hypothesis form. (A brief description of hypothesis testing is found in Appendix C.) The two conditions are as follows:

Condition one

H_0: Argentine losses, when British have SI, are equal to or less than Argentine losses when Argentine have SI.

H_a: Argentine losses, when British have SI, are greater than Argentine losses when Argentine have SI.

Condition two

H_0: British losses, when Argentines have SI, are equal to or less than British losses when British have SI.

H_a: British losses, when Argentines have SI, are greater than British losses when British have SI.

The hypotheses under consideration suggest collecting data on one individual when exposed to two independent conditions, i.e., playing with and without SI. This type of testing requires an analysis of paired data (8:343-350). Each condition above was tested on the two players chosen for the paired data analysis. This resulted in four hypothesis tests.

To insure that the data collected was dependent upon the player making the inputs to the game, a test for independence between the players and their scores was determined to be necessary. This, then, became the first test of interest. Without insuring that the scores are dependent upon the player, the original design of the experiment, concerned with a change to only the model, could not be tested. The tests would otherwise reflect changes in both the model and the input data. The chi-square test of independent proportions was used to make this determination (16:342-356).

Of equal interest in this experiment were the consequences with several players participating. This would change the input data to the model and add a new dimension to the model results. Once again, the only factor available for measuring output results was the number of points awarded for defeating an opponents' war fighting assets. Since the model and the input data would change, because of varied participants, the analysis needed to focus on the difference between the losses and the style of play, i.e., original model and modified model. The focus question remained, is there a change in one opponents' losses when playing with or without SI. However, since the input data would likely change with varied participants, a paired analysis could not be considered. The alternative was to consider a difference between two means. This procedure examined the mean scores received when playing with and without SI. A test for determining the difference between two population means could be used to detect what impact SI had on the losses (8:322-340).

The possible conditions for consideration were:

1) British mean score with SI
2) British mean score without SI
3) Argentine mean score with SI
4) Argentine mean score without SI

If conditions one and four are compared, the results are the original design of the game. If two and three are compared, the results indicate the modified game. To receive insight into what effect SI has on losses, a comparison between playing with and without SI is required. Also, to determine how each sides' strength is effected by SI, a comparison between each sides' score with and without SI is needed. This lead to the following comparisons:

1 to 4   British with SI vs Argentines without SI

2 to 3   British without SI vs Argentines with SI

1 to 2   British mean score with and without SI

3 to 4   Argentine mean score with and without SI

1 to 3   Losses when each side has SI

2 to 4   Losses when each side lacks SI

The hypothesis tests which showed these results are as follows:

Condition one

H_0: The mean British score, when the British have SI, is equal to or less than the mean Argentine score when the British have SI.

H_a: The mean British score, when the British have SI, is greater than the mean Argentine score when the British have SI.

Condition two

H_0: The mean British score, when the Argentine have SI, is equal to or less than the mean Argentine score when the Argentine have SI.

H_a: The mean British score, when the Argentine have SI, is greater than the mean Argentine score when the Argentine have SI.

Condition three

H_0: The mean British score, when the British have SI, is equal to or less than the mean British score when the Argentine have SI.

H_a: The mean British score, when the British have SI, is greater than the mean British score when the Argentine have SI.

Condition four

H_0: The mean Argentine score, when the Argentine have SI, is equal to or less than the mean Argentine score when the British have SI.

H_a: The mean Argentine score, when the Argentine have SI, is greater than the mean Argentine score when the British have SI.

Condition five

H_0: The mean British score, when the British have SI, is equal to or less than the mean Argentine score when the Argentine have SI.

H_a: The mean British score, when the British have SI, is greater than the mean Argentine score when the Argentine have SI.

Condition six

H_0: The mean British score, when the Argentine have SI, is equal to or less than the mean Argentine score when the British have SI.

H_a: The mean British score, when the Argentine have SI, is greater than the mean Argentine score when the British have SI.

Before these tests could be accomplished, it was necessary to insure that the losses which resulted in play were dependent upon the style of play. If the losses, which determine scores, were shown to be independent of the st.le of play, then the mean scores used in these tests provided no additional, useful information. To check for dependence, the chi-square test of independent proportions was used.

A summary of the four types of tests considered for this experiment included:

1) a check for independence between players and their scores using the chi-square test of independent proportions

2) results due to the model change using hypothesis testing of paired data

3) a check for independence between the losses and the method of play using the chi-square test of independent proportions, and

4) results found with varied participants using hypothesis testing of the difference between two population means.

These four tests provided the statistical tools necessary to determine what impact SI has on the model in question. The equations used with these four tests are further explained in Appendix D.

Test Statistics. The next step in the design of the experiment dealt with determining the critical values of the test statistics. Kachigan suggest that with any hypothesis testing, the importance of choosing an appropriate sample size, n, is based on practical considerations. The questions which needed to be considered dealt with the consequences of reaching an incorrect conclusion with a statistical test. If making an error can result in loss of life, the significance level and power of the test require greater precision than may be necessary when conducting a poll of consumer preference (16:192). Due to the variability expected in player inputs along with many simplified assumptions covered in the game's rules, a significance level of $\alpha = 0.10$ and power of the test set at $1-\beta = 0.90$ would be used to establish the desired sample size.

Knowing α, $1-\beta$, the true population parameter value, η, and the population standard deviation, σ, one can compute the required sample size to meet these conditions (16:189-192). For this experiment, the population parameters were not known. To determine some idea of what values would be appropriate, recorded history of the Falklands war was explored.

The war game chosen in this experiment, *The Falklands War*, is an attempt to simulate the conflict over the islands of the same name. Researching the actual outcome of the Falklands conflict and applying the same scoring procedure found in the game to actual results, the estimated population parameter needed for determining an appropriate sample size was identified. By applying historical data, the estimated population parameters would be more realistic. The computations for determining the historical data values are found in Appendix E.

While the values computed in Appendix E are only estimates, a combination of α, $1-\beta$, mean scores, and varying standard deviations were calculated to determine a range of sample sizes. This range assured a pre-determined significance level and power of the test, assuming the sample parameters agreed with the estimated parameters. This method helped identify, before data collection, an approximate number of samples needed to perform the hypothesis testing. The calculations for this range of sample sizes were performed using a software package called *Powerpack* and the results of these calculations are found in Appendix F.

Decision Rule. The chi-square test for independent proportions, the test for paired data, and the test of the difference between mean scores each have a critical value. These values were based on the level of significance and the degrees of freedom found in the sample. The decision rule for rejecting the null hypothesis consisted of a comparison between the test statistic and the critical value. The critical value used for this comparison was found in Devore's textbook (8:635-636). The results of the comparison determined the outcome of the test. Though this comparison was the primary means for determining the outcome of the test, the p-value and power of each test was also computed to collect additional information for a sensitivity analysis of the results.

Design Summary. The design of the experiment consisted of stating what parameters in the model could be used to provide information concerning the impact SI had on the model. Once this parameter was determined, the tests needed to collect knowledgeable information were identified. The test statistics, which included setting measures of test effectiveness, were next outlined. Once this was accomplished, the decision rule for determining test results was specified. The next step in performing the experiment was collecting the data.

Data Collection and Analysis

The process of collecting the data involved playing the game. Though some would consider this type of data collection fun, it proved to be the most time consuming and, eventually, challenging aspect as well. The selection of participants required finding a body of players willing to dedicate several days to game playing. This proved to be a weakness in the design of the experiment. It was determined that one replication of the game required an average of eight hours. Unfortunately, this was not discovered until after data collection had begun. The consequences are noted in the results found in Chapter IV.

The analysis of the data involved applying the predetermined equations to the data collected. This was a matter of selecting the appropriate data for the hypothesis in question, calculating the sample statistic and comparing this value to the critical value. *Powerpack* was employed to determine the p-value and power of each test. These values allowed sensitivity analysis of the findings. The results from the analysis are found in the following chapter. With data collection and analytic work completed, the final process of this experiment required stating the results and making recommendations based on the findings.

Recommendations

The final chapter of this thesis centers on the conclusions which were drawn from the statistical analysis. These results help support the answer to the question concerning eliminating portions or adding assets to a model in an effort to save costs or improve model performance. With this question answered, recommendations are presented which conclude this research.

IV. RESULTS

Introduction

This chapter presents the results of the tests conducted on the data collected from the playing of *The Falklands War*. The statistical tests are discussed in the previous chapter. The following notation is used in presenting the findings:

Blue represents the Argentine player

Red represents the British player

"A" represents the game played with the Argentine player having satellite information

"B" represents the game played with the British player having satellite information

The notation

Blue mean score / "A"

indicates:

The average score of the Argentine player when the game is played with the Argentine player having satellite information.

Red mean losses / "B"

indicates:

The average losses suffered by the British player when the game is played with the British player having satellite information.

The test results are as follows:

Pre-sampling statistical analysis

The results of the pre-sample statistical analysis produced the following suggested sample size range to give $\alpha = 0.10$ and $1-\beta = 0.90$. The numbers inside the table represent the required sample size for the given parameters. See Appendix F for the list of computed values and the computer code used to generate these results.

For the paired t-test:

		σ		
		2.0	2.5	3.0
$mu\text{-}d_a$	2	8	12	16
	3	5	6	8

In the game, *The Falklands War*, the points awarded for sinking one ship ranged from three to six, depending on the strength of the ship. It was felt that a significant difference to the results would occur if intelligence information prevented the loss of one ship. Therefore, a $mu\text{-}d_a$ value of three was set and the results required a target sample size of five paired games when the estimated standard deviation was two. Since the game is played with two players and each player is given the opportunity to play both sides, the needed sample size is doubled. This requires 10 games played with British having satellite information and 10 games played with Argentine having satellite information. A total of 20 games are therefore required to do the analysis of modification changes only to the model.

For the difference of means test:

		σ 2.0	2.5	3.0
delta	2	14	22	30
	4	4	6	8

These results show equivalent trends to those found with the paired t-test. This test requires a larger sample size than found necessary for the previous test. Accepting two as the significant difference between mean scores requires 14 games when British have satellite information and 14 games when Argentine have satellite information assuming the sample standard deviation is two. This then requires a total of 28 games be played. It was decided that the games played by only two players for the paired analysis could be combined with games played by varying participants to meet the required 28 game sample size.

Analysis of Collected Data

Before presenting the results of the test conducted on the data collected, it is necessary to point out the weakness of the data. The required sample sizes were not achieved. Before data collection began, it was felt one replication of the game could be accomplished in about two to three hours. This was the information given to the participants when recruiting their assistance. Once data collection began, this figure was quickly discovered to be in error. Consequently, the participants became less willing to play and eventually were required to cease play due to other commitments.

Through the data collection process, the players and their varied strategies were observed. Participants quickly learned the objectives of the game and began gaming the game, i.e., finding ways to beat the rules. This introduced a much higher degree of variance than was anticipated. Consequently, the sample size needed to show a significant difference increased above the target level. Based on the sample standard deviation from the data collected, the required sample sizes doubled.

Because of player unavailability and the high degree of variability observed, it was felt that before starting a new data collection process, analysis of the data collected thus far should be accomplished and observations noted. The estimated expense in man-days needed to reach the target sample size, after having collected this data, was determined to be approximately 180 days. Scheduling games and committing players needed to reach the new target sample size of over 50 games may take as much as one man-year to collect all the data. It was felt that unless the data collected thus far showed significant evidence supporting this type of research, further pursuit in the analysis of a board game using the techniques outlined herein would not warrant the expense required.

The results of the data collected are found on the following pages.

Test #1: Test for independence between victory points and players involved.

H_o : Scores and Players are independent

H_a : Scores and Players are dependent

df = (4-1)(2-1) = 3

$X^2_{.10,3} = 6.251$

	Players		
Scores	Tim	John	Totals
Blue / "A"	$\boxed{19.9}$ 20	$\boxed{29.1}$ 29	49
Blue / "B"	$\boxed{37.8}$ 60	$\boxed{55.2}$ 33	93
Red / "A"	$\boxed{55.6}$ 43	$\boxed{81.4}$ 94	137
Red / "B"	$\boxed{48.7}$ 39	$\boxed{71.3}$ 81	120
Totals	162	237	399

X^2 statistic = 30.14

X^2 statistic > $X^2_{.10,3}$,

therefore, REJECT THE NULL HYPOTHESIS and conclude that Scores and Players are dependent upon one another.

Test #2 : Hypothesis testing of paired t statistics. P-value and Power are computed using sample standard deviation and mu-d_a = 3.

Test A John's Data

H_o : Blue Mean Losses / "B" = or < Blue Mean Losses / "A"

H_a : Blue Mean Losses / "B" > Blue Mean Losses / "A"

df = 2

$t_{.10,2} = 1.886$

$$t_{paired} = 0.50$$

$$t_{paired} < t_{.10,2},$$

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.3334

Power of the Test = 0.1902

Test B John's Data

H_o : Red Mean Losses / "A" = or < Red Mean Losses / "B"

H_a : Red Mean Losses / "A" > Red Mean Losses / "B"

df = 5

$t_{.10,5} = 1.476$

$$t_{paired} = 2.774$$

$$t_{paired} > t_{.10,5},$$

therefore, REJECT THE NULL HYPOTHESIS and conclude that British losses are greater when Argentine has SI.

P value = 0.0196

Power of the Test = 0.8935

Test C Tim's Data

H_o : Blue Mean Losses / "B" = or < Blue Mean Losses / "A"

H_a : Blue Mean Losses / "B" > Blue Mean Losses / "A"

df = 5

$t_{.10,5} = 1.476$

$$t_{paired} = 0.675$$

$$t_{paired} < t_{.10,5},$$

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.2647

Power of the Test = 0.2542

Test D Tim's Data

H_o : Red Mean Losses / "A" = or < Red Mean Losses / "B"

H_a : Red Mean Losses / "A" > Red Mean Losses / "B"

df = 2

$t_{.10,2} = 1.886$

$$t_{paired} = 0.658$$

$$t_{paired} < t_{.10,5},$$

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.2892

Power of the Test = 0.2261

Test #3 : Test for independence between losses and the method of play (i.e., who has satellite information).

H_o : Losses and Satellite Information are independent

H_a : Losses and Satellite Information are dependent

df = (4-1)(3-1) = 6

$X^2_{.10,6}$ = 10.645

	Losses			
Scores	Ships	Aircraft	Troops	Total
Blue / "A"	141.4 / 136	49.3 / 66	38.3 / 27	229
Blue / "B"	164.3 / 164	57.2 / 48	44.5 / 54	266
Red / "A"	98.8 / 103	34.4 / 29	26.8 / 28	160
Red / "B"	149.5 / 151	52.1 / 50	40.5 / 41	242
Totals	554	193	150	897

X^2 statistic = 13.94

X^2 statistic > $X^2_{.10,6}$,

therefore, REJECT THE NULL HYPOTHESIS and conclude that Losses and Satellite Information are dependent on one another.

Test #4 : Hypothesis testing involving t statistic of two means. P-value and Power are computed using the sample standard deviation and a delta = 4.

Test A: Condition one

H_o : Red Mean Score / "B" = or < Blue Mean Score / "B"

H_a : Red Mean Score / "B" > Blue Mean Score / "B"

df = 10

$t_{.10,10} = 1.372$

$$t_{statistic} = 1.358$$

$$t_{statistic} < t_{.10,10},$$

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.1037

Power of the Test = 0.7395

Test B: Condition two

H_o : Red Mean Score / "A" = or < Blue Mean Score / "A"

H_a : Red Mean Score / "A" > Blue Mean Score / "A"

df = 10

$t_{.10,10} = 1.372$

$$t_{statistic} = 0.574$$

$$t_{statistic} < t_{.10,10},$$

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.2901

Power of the Test = 0.7416

Test C: Condition three

H_o : Red Mean Score / "B" = or < Red Mean Score / "A"

H_a : Red Mean Score / "B" > Red Mean Score / "A"

df = 10

$t_{.10,10} = 1.372$

$t_{statistic} = 1.13$

$t_{statistic} < t_{.10,10}$,

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.1439

Power of the Test = 0.8094

Test D: Condition four

H_o : Blue Mean Score / "A" = or < Blue Mean Score / "B"

H_a : Blue Mean Score / "A" > Blue Mean Score / "B"

df = 10

$t_{.10,10} = 1.372$

$t_{statistic} = 1.44$

$t_{statistic} > t_{.10,10}$,

therefore, REJECT THE NULL HYPOTHESIS and conclude that Argentine will perform better with the aid of SI.

P value = 0.0923

Power of the Test = 0.6407

Test E: Condition five

H_o : Red Mean Score / "B" = or < Blue Mean Score / "A"

H_a : Red Mean Score / "B" > Blue Mean Score / "A"

df = 10

$t_{.10,10} = 1.372$

$$t_{statistic} = 0.31$$

$$t_{statistic} < t_{.10,10},$$

therefore, FAIL TO REJECT THE NULL HYPOTHESIS indicating no significant information can be drawn from this test.

P value = 0.3821

Power of the Test = 0.6892

Test F: Condition six

H_o : Red Mean Score / "A" = or < Blue Mean Score / "B"

H_a : Red Mean Score / "A" > Blue Mean Score / "B"

df = 10

$t_{.10,10} = 1.372$

$$t_{statistic} = 2.10$$

$$t_{statistic} > t_{.10,10},$$

therefore, REJECT THE NULL HYPOTHESIS and conclude British are stronger without SI than when Argentine is without SI.

P value = 0.0329

Power of the Test = 0.9455

Summary

This chapter has presented the results of the statistical analysis performed on the data collected from playing of *The Falklands War*. Inferences concerning the results are discussed in the following chapter along with recommendations concerning this and future studies.

V. Conclusions and Recommendations

The objective of conflict is to minimize the losses to oneself and allied forces while trying to maximize the damage to an opponent. Combat models take this approach as they attempt to determine what the outcome of a conflict will be when certain conditions are employed. This study considered one such factor for conflict where each side, independently, was afforded the advantage of satellite information. The results of modeling these conditions were analyzed considering first, the losses associated with the player involved in the decision making when only the model is changed and second, the losses as they relate to the satellite information when both the model is changed and the participants vary. This chapter will address the findings for each condition and conclude with recommendations.

Player impact on losses

Two tests were used to determine what impact the player has on the outcome of the model. The first test determined if indeed a relationship exists between the results and the players. The second test considered the losses incurred with decisions made by one individual.

Initially, it was assumed the resultant scores were dependent upon the player involved. The chi-square test for independence provided the evidence necessary to justify this claim. Having decided that the scores were a function of the player, the second test looked at the results from two players. Each player was examined independently. The losses incurred when supplied with satellite information versus when lacking satellite information were compared. The results for the two players varied significantly.

The first player, John, provided evidence supporting the idea that if one side is supplied satellite information, that side will have the advantage. This was observed particularly when John played the role of the British. However, when John played the role of the Argentine forces, his losses were equally as high with the satellite information as when his opponent had the advantage of that additional information. An observation noted during play indicates John was a very aggressive player. He recognized the superior fire power awarded the British forces in the design of the game and elected to take severe losses in an attempt to cripple the British fleet. This strategy likely defeated the relevance of satellite information during the games where he played the role of the Argentine forces.

The evidence provided by the second player showed relatively no advantage to one side or the other when having satellite information. The results indicated heavy losses to the Argentine force, when played by Tim, regardless of who had the satellite information. When Tim played the

British forces, the losses were essentially the same under both methods of play. The only observation noted concerning this player was Tim's perception of the British forces' strength. This strength appeared much greater than that of the Argentine forces and Tim suffered fewer losses overall when playing British as opposed to playing Argentine. However, the statistical tests provided no evidence that the satellite information had any impact on the losses Tim suffered while playing the game.

Satellite Information Impact on Losses

This series of tests was used to determine if a relationship exists between the losses and the method of play. These tests considered all twelve games played by varying players under different roles. The first test looked for dependence between the style of play and the losses. The second test compared victory scores under the two styles of play.

A definite relationship between the player's score and the method of play was shown with the chi-square test for independence. This test provided evidence supporting the claim that losses of ships, aircraft, and troops are dependent upon which player has satellite information. To verify this conclusion, mean scores from all games played were compared.

Under the conditions established before testing began, only one of the six tests strongly support the notion that satellite information has an impact on victory scores. One other test provided evidence to support this claim. The strongly supporting test indicated the British force was much stronger than the Argentine force when both sides lacked satellite information. The second supporting test indicated Argentine would perform better with the aid of satellite information. These tests were conducted at a .10 level of significance. By considering the P-value in all tests, two of the four tests which failed to support the advantage of satellite information failed by only a small margin. If one is willing to accept the probability of being incorrect 15 percent of the time, four tests support the role satellite information had on the outcome of the game. This will also reduce the required sample size somewhat. The only scenarios which did not provide supporting evidence were when the Argentine forces had satellite information.

Final Outcome

The results, after having completed an analysis of all possible combinations of the data, simply fail to show any significant information. The lack of sufficient data was determined to be the primary reason. However, from the data collected, little is observed which indicates playing satellite information in a board game, similarly to what has been done here, will produce the evidence needed to justify modifications to more extensive and complex models. The requirement still exists to determine what impact satellite provided data will have on a model. Though it was hoped that an analysis of playing satellite information within a board game could provide such understanding, this research suggests otherwise.

Modeling combat is a complex process requiring substantial amounts of time and effort. Though this study had hoped to show that results from one simulation of combat may not always provide correct information, the evidence is just not there. Combat will never be fought exactly as a simulation predicts. For this reason, modelers can only hope to provide some insight into possible engagements. Though statistics thrive on large sample sizes, no matter how many times the simulation is run and what the statistics claim, the results will never equal reality. Models cannot be expected to "predict" future events. They can give only insights into how several factors relate when compared under defined conditions. It is therefore critical that decision makers recognize the modeling process for what it is and not the results for what they say.

Recommendations

At the beginning of this study, it was hoped the evidence found would provide significant support indicating a degree of difference in combat models simulating satellite data and those which have no such data available. Unfortunately, the supporting evidence was not found. The impact, on this particular model, of changing the input parameters was minimal. If further research in the area of board games is considered, the following recommendations should be observed.

1. Limit the players selected for data collection to only two individuals.

2. Allow these two players a learning period of two games before collecting data.

3. Consider, for possible players, only those familiar with war games.

4. Use actual commanders who may be involved in force deployments.

If only two individuals are used in collecting data from several runs of this model, the variability associated with each decision will be reduced. The individuals which played this game demonstrated different decision making processes. Though this research allowed exploration of many possible strategies, it compounded the parameters which affect the games' outcome. This distracted from the focus on the single effects of satellite information to game results.

Players of war games learn more about the two force structures through playing the game than by simply reading the rules. If each player is given the opportunity to play two games, this allows the player a chance to represent each side once and develop a feel for that forces' strengths and weaknesses. This two game warm up period will eliminate the learning curve participants experience when first beginning to play and provide data which is more consistent with an established strategy that player wishes to pursue.

War games are a unique modeling tool. Though often thought of as simply means of entertainment, they can provide valuable information. Individuals familiar with war games, referred to as war gamers, understand the thought process behind the development of the game. This understanding helps the participants develop strategies consistent with the thought processes actual decision makers might employ in times of war. War gamers, therefore, spend less time trying something new and focus their attention on the strengths and weaknesses of the forces being modeled.

War games, of theater level conflict, consist of a series of decisions often made by high ranking political and military commanders. When actual military commanders are used in the decision process, the results have proven to be rather accurate. The war games played by the Japanese leaders prior to the attacks on Pearl Harbor and Midway are but two examples (27:2). The employing of actual combat decision makers will improve the realism of the game and therefore, should demonstrate a more accurate impact of what satellite information has on game results.

Based on the experience of this research and the recommendations stated above, a future study might consider including games played at advanced military education schools. War games are played at such schools as Squadron Officers School, Air Command and Staff College, and Air War College, however, the results of these games are seldom maintained. Two versions of the same game could be developed for the US Air Force Air War College. One version would include satellite assets and the other would not. The students would play the games over a period of years without knowing which version of the game they were playing. The results could be tallied and an analysis conducted on the data. Though this study would involve several participants, the findings may be a way of showing the role satellite information has on combat modeling. This approach would complete academic requirements of the service schools and minimize the cost of data collection to the analyst.

This study has failed to indicate what impact satellite information has on a model when several decision makers are involved. Though a study has been recommended involving several participants, it is still believed that by limiting the number of decision makers to two, giving these players a two game learning period, and using actual commanders experienced with war games, the results will show more of the impact created by the satellite information and less of the human decision making element. The human element found in this study appears to have introduced greater variability than was expected. Limiting this variance should be considered a high priority when pursuing further research with war games.

Further, it is important to note that war games are time consuming and consequently costly. Though information can be gleaned from playing games, this research supports the thoughts of Bonder when he said, "this type of model is not a feasible mechanism for analyzing a broad spectrum of system alternatives in a responsive manner to meet planning cycle requirements" (4:73).

Conclusion

This study has focused on combat modeling and the role satellite information has therein. An introduction to the difficulties associated with modeling complex occurrences was presented. A war game, used to simulate conflict between two opposing forces, was employed to determine what impact a change to the model might have on the outcome. Though some change was noted, the evidence suggesting a significant degree of change was lacking. The recommendations for further study into this area deal with limiting the human decision factors found in gaming.

Appendix A: Data Collected from Playing The Falklands War

Game Results
Two Player Only

Game Style	"A"		"B"		"A"		"B"		"A"		"B"	
Date of Play	14 Sep 88		6 Sep 88		19 Sep 88		20 Sep 88		21 Sep 88		22 Sep 88	
Players Name	John	Tim	John	Tim	Tim	John	Tim	John	Tim	John	Tim	John
Color	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
Lost Ships	33	14	29	19	29	14	23	22	19	0	20	18
Lost Aircraft	10	9	6	10	15	4	9	7	15	1	13	6
Lost Troops (Company Size)	0	6	4	4	0	0	10	3	16	1	6	4
Total Victory Points	29	43	33	39	18	44	32	42	2	50	28	39

Game Results
Multiple Players

Game Style	"A"		"B"		"A"		"B"		"A"		"B"	
Date of Play	5 Sep 88		12 Sep 88		8 Sep 88		16 Sep 88		26 Sep 88		27 Sep 88	
Players Name	Ron	Jim	John	Mike	John	Jim	Ron	John	Tim	Mike	Jim	Tim
Color	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
Lost Ships	21	21	25	41	18	31	41	18	16	23	26	33
Lost Aircraft	4	2	4	6	8	10	8	14	14	3	8	7
Lost Troops (Company Size)	0	0	10	18	3	17	14	2	8	4	10	10
Total Victory Points	23	25	65	39	58	29	34	63	30	38	50	44

"A" Indicates the game was played with the Argentine player moving first

"B" Indicates the game was played with the British player moving first

The player moving first represents his lack of Satellite information

Blue is the color representing the Argentine Forces

Red is the color representing the British Forces

Players involved with data collection were:

John Barry   Tim Cordner   James Dalzel   Ronald Harrison   Michael Worthington

Appendix B: Description of the Game *The Falklands War*

> *The Falklands War* is a two player simulation of the conflict fought over the islands of the same name. Play starts on the 1st of May, 1982 and ends by either a diplomatic resolution of the crisis or the defeat of one side by the other. The game is played in a series of game turns in which players alternate moves and combat according to the Sequence of Play rules. Victory is determined by victory points awarded for destroying enemy units and capturing military objectives. (6:2)

This game is played upon a 22" x 24" map sheet showing the South Atlantic around the Falklands and a portion of the Argentina coastline. The map is laid out with hexagons representing 20 nautical miles. This provides a means of determining movement within one turn. Each turn represents two days of time.

Each side is equipped with ground troops, surface and submarine vessels, and aircraft according to the reports generated from the actual battle. These troops, ships, and aircraft are represented on small playing pieces, colored blue and red, indicating size and strength of the men and equipment. Reinforcements are provided throughout the course of play similarly to what actually occurred.

The game begins with the Argentine forces occupying the Falkland islands and the British forces positioned at sea within striking range. The British forces, due to diplomatic circumstances, are limited to a 200 nautical mile blockade zone around the islands. This will change, as the game progresses, to allow the British forces to attack anything outside 12 miles of the Argentine coastline. Authorization to invade the islands is delayed until late in the game and after invasion is permitted, the crisis is resolved. Each one of these changes in diplomatic circumstances is determined by the roll of a die after each turn is completed.

Each turn consists of receiving reinforcements, determining the weather, surface movement, submarine movement, aircraft movement, combat phases, ground movement and attack, damage repair and construction, and finally diplomacy. The movement of each unit is designed to represent that units actual capability, with weather playing a role in reducing movement under adverse conditions. The combat phase compares the strengths of each opposing force, based on each players decision to engage, and uses a decision look-up table, with the role of die, to determine the outcome. Damage repair and construction is determined stochastically if properly equipped to repair or construct airfields. The diplomacy track, as described above, is advanced with the role of a die.

Victory points are awarded when one player defeats an opponents assets. These come from destroying ships, aircraft, ground troops, and occupied territory. The value of points is determined by the combat capability of the asset. Once the diplomacy track has reached "crisis resolved", each player's total victory score determines the game outcome. If the difference between scores is ten or less, the victory is considered only marginal. A decisive victory requires accumulating 21 points more than the opponent. The game is allowed a maximum of 30 turns, however, it usually ends as the result of a diplomatic solution.

The designer of the game gives tips to each player pointing out their strengths and weaknesses. The Argentine player is supplied with a superior air force and told to take advantage of this strength. He is also warned of the strength of the British ships over his own. Direct engagement with the British fleet is discouraged. The British player is provided virtual control of the sea; however, the lack of air cover is a weakness. This player is encouraged to carefully plan air to air engagements which will result in his favor. The ultimate goal is control of the Falkland islands when the conflict is re[illegible]. Argentine begins the game in control of the island and warned to fight to the bitter end before giving up land. The British are hindered from control of the islands until diplomacy allows. This common objective of controlling a small portion of land caused *The Falklands War*.

Appendix C: Hypothesis Testing

Sample observations are used to derive statistics which approximate population parameters from which the sample came. The use of hypothesis testing is to use these "sample statistics to support or discredit *a priori* hypotheses, or speculations, about the true value of the population parameter" (16:160). A hypothesis about the population parameters is established, and then, a sample taken from the population is used to test the likelihood of the hypothesis being true. This probability of being true cannot be 100 percent certain and consequently introduces a level of significance into the test.

The level of significance found in hypothesis testing is associated with the possible errors in judgement a researcher may make. Kachigan outlines these possible conditions using the outcomes from a jury trial as an example. The true state of affairs for the defendant are innocent or guilty. The jury can produce a verdict of innocent or guilty as well. If the defendant is truly innocent and the jury finds him innocent, a correct choice was made. If the defendant is truly guilty and the jury finds him guilty, again a correct choice was made. If the defendant is guilty and found innocent, or innocent and found guilty, two types of errors were made (16:168-169).

Test of an hypothesis H_0

Conclusion of statistical test	True state of affairs: H_0 is true	True state of affairs: H_0 is false
H_0 is not rejected	$(1-\alpha)$ Correct conclusion	(β) Type II error
H_0 is rejected	(α) Type I error	$(1-\beta)$ Correct conclusion

Figure 5. Hypothesis choice and the associated error (Adapted from 16:169).

In hypothesis testing, these errors are referred to as Type I and Type II errors. Figure 5 illustrates these conditions. A Type I error will occur with a probability set at a level of significance, α. A type II error will occur with a probability set at a level of β. These parameters dictate the probability of making a correct choice.

When working with hypothesis testing, a researcher will seek to find an alternative hypothesis true; i.e., reject H_0. However, when doing this, he wishes to insure the results are true. To correctly reject H_0 when indeed it is false occurs at a probability of $1-\beta$. This value is referred to as the power of the test. The greater the power of the test, the better the decision rule, and hence the less likely chance of making an error when selecting the alternative hypothesis (16:160-188).

Christensen points out the important relationship between α and β.

> There are two ways in which this power of the function can be enlarged. Because of the relationship between α and β, one can accept a larger α and thus decrease β, the net effect being an increase in $1-\beta$, the power of the function. The second method is that of increasing the sample size. The closer the sample comes to representing the universe, the more likely one is to choose S_1 (reject H_0) as the real state of nature when in fact it is true, $1-\beta$ approaches 1. (5:176)

He goes on to point out that researchers should not get caught-up in always selecting $\alpha = .05$ or $\alpha = .01$. "Meaningful hypothesis testing requires the significance level to be a decreasing function of the sample size" (5:176). For this reason, regardless of the sample size and the pre-determined significance level , a sensitivity analysis of the data involving α and β will provide greater insight into how well the sample supports the hypothesis.

Appendix D: Test Equations

The analysis of the data collected was accomplished using the following four tests.

Test #1. The first test was to check for independence between players and their scores. The chi-square test of independent proportions was used to make this determination (16:342-356). The test consisted of a null and alternative hypothesis as follows:

H_o = Scores and Players involved are independent

H_a = Scores and Players involved are dependent

This test took the scores for the games involved and determined the chi-square (X^2) statistic using the following equation and matrix:

$$X^2 \text{ statistic} = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i$$

where

O_i = Observed values E_i = Expected values

The following notation is found on the next page to identify the score used in calculating the chi-square statistic.

Blue represents the Argentine player

Red represents the British player

"A" represents the game played with the Argentine player having satellite information

"B" represents the game played with the British player having satellite information

	Players		
Scores	Tim	John	Totals
Blue / "A"	E Observe	E Observe	
Blue / "B"	E Observe	E Observe	
Red / "A"	E Observe	E Observe	
Red / "B"	E Observe	E Observe	
Totals			

E = Expected Value   Observe = Observed Value

The expected value is calculated by multiplication of the row total with the column total and this product divided by the sum of the row totals (which is also the sum of the column totals). Degrees of freedom (df) for the chi-square statistic were determined by:

$$df = (r-1)(c-1)$$

where r = number of rows and c = number of columns. Rejection of the null hypothesis occurs when

$X^2_{statistic} \geq X^2_{\alpha,df}$

Test #2. The second test used was a paired t statistics (8:343-349). This test requires independent samples. It is assumed the samples used in this analysis are independent. The paired t test considers one set of two individuals and two observations made on each individual. The paired t statistic was determined using the following equation:

$$t_{paired} = \frac{d}{s_D/(n)^{1/2}}$$

where d and s_D are the sample mean and standard deviation, respectively, of the differences between observations. The rejection region for the hypothesis tests occurred when

$$t_{paired} \geq t_{\alpha,n-1}.$$

Test #3. This test used the chi-square statistic to check for independence between the losses and the method of play (i.e. who has the satellite information). The chi-square test of independent proportions was again used to make this determination (16:342-356). The test consisted of a null and alternative hypothesis as follows:

H_o = Losses and satellite information are independent
H_a = Losses and satellite information are dependent

This test used the scores for all games and determined the chi-square (X^2) statistic using the following equation and matrix:

$$X^2 \text{ statistic} = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i$$

	Losses			
Scores	Ships	Aircraft	Troops	Total
Blue / "A"	E Obs	E Obs	E Obs	
Blue / "B"	E Obs	E Obs	E Obs	
Red / "A"	E Obs	E Obs	E Obs	
Red / "B"	E Obs	E Obs	E Obs	
Totals				

E = Expected Value   Obs = Observed Value

Once again, rejection of the null hypothesis occurred when

$$X^2_{statistic} \geq X^2_{\alpha,df}$$

Test #4. The final test, considering the losses and the method of play, was a two sample t test. Two assumptions needed to be satisfied before the test could be validated. These assumptions are, the mean scores of the blue player and the red player, under both methods of play, came from normal population distributions, and the values of the population variances under these conditions are equal. These assumptions allowed the use of a pooled estimator of the common variance σ^2, denoted by S_p^2. With this common variance, the test statistic value was computed using the following equation:

$$t = \frac{\dot{x} - \dot{y}}{S_p\ ((1/m) + (1/n))^{1/2}}$$

where $\dot{x}$ and $\dot{y}$ represent the two sample means, m and n represent the number of samples of x and y respectively, and S_p represents the pooled standard deviation estimator (8:334-337). Rejection of the null hypothesis occurs when

$$t_{statistic} \geq t_{\alpha, m+n-2}.$$

Appendix E: Population Parameters

The following matrix indicates the lost assets which were recorded during the Falklands war (12:vi-vii). The points awarded are the values assigned these assets in the game *The Falklands War* and indicate how the game would have scored the actual conflict (6).

Lost Assets			Points Awarded To British	Points Awarded To Argentine	Difference
Ships	Santa Fe	(A)	6		
	Sheffield	(B)		2	
	General Belgrano	(A)	4		
	Ardent	(B)		3	
	Antelope	(B)		3	
	Conventry	(B)		1	
	Atlantic Conveyor	(B)		2	
SUBTOTAL			10	11	-1
Aircraft	43+	(A)	12		
	0	(B)		0	
SUBTOTAL			12	0	12
Troops (Captured or killed)	2000+	(A)	8		
	50+	(B)		0	
SUBTOTAL			8	0	8
GRAND TOTAL			30	11	19

(A) = Argentine Owned   Argentine Score = 11
(B) = British Owned   British Score = 30

Difference in losses = d = 19/3 = 6.33

It was felt that satellite information should aid in preventing loss of war fighting capability. If the added information could prevent the loss of one less ship, this would be a significant improvement. The value of this ship in the model ranges from 2 to 4 depending on the ship's strength. These values were used as the range of delta values between the null and alternative hypothesis computations for determining the range of sample sizes.

Appendix F: Sample Size Range Computations

Sample size for paired data analysis

This first computer program was used to determine a range of sample sizes for the paired t-test, which would meet a significance level of $\alpha = 0.1$ and a power of the test of $1-\beta = 0.9$. The hypothesized mean difference was allowed to vary from 2 to 4 points and the standard deviation was allowed to vary from 2 to 3. The results follow the program (19).

```
$ * FILE: rsptss.pwr (28)
$ *-----------------------------------------------------;
$ TEST One Sample Right-Sided Paired t-Test ;
$ *-----------------------------------------------------;
$ * This is a Test Concerning the MEAN of DIFFERENCES;
$ * of a Normal Population of Differences ;
$ * with UNKNOWN Variance (SMALL-SAMPLE TEST);
$ *------------------------------------------------------;
$  Type = t, right; df=n-1; Alpha = siglev;
$  H0nc = (muD0-muD0)/(stdDbar/sqrt(n));
$  H1nc = (muDA-muD0)/(stdDbar/sqrt(n));
$ *------------------------------------------------------;
$ * Below we declare a variable to place the Power;
$ * of the test into and retain this variable and;
$ * the one or more alternate values of mu so we;
$ * can plot the Power Function;
$ *-------------------------------------------------------;
$  PwrVar = PowerOfTest; retain PowerOfTest,muDA,stdDbar,n;
$ *-------------------------------------------------------;
$ prompt muD0, muDA, siglev, Dbar, stdDbar, n;
$ run;

Enter muD0, muDA, siglev, Dbar, stdDbar, n :
0,2(1)4,.1,6.33,2(.5)3,3(3)30

Variable: PowerOfTe      muDA   stdDbar         n

Obs    1:      0.531      2.00       2.00       3.00
Obs    2:      0.829      2.00       2.00       6.00
Obs    3:      0.940      2.00       2.00       9.00
Obs    4:      0.980      2.00       2.00       12.0
Obs    5:      0.993      2.00       2.00       15.0
Obs    6:      0.998      2.00       2.00       18.0
Obs    7:      0.999      2.00       2.00       21.0
Obs    8:      1.000      2.00       2.00       24.0
Obs    9:      1.000      2.00       2.00       27.0
Obs   10:      1.000      2.00       2.00       30.0
```

Variable:	PowerOfTe	muDA	stdDbar	n
Obs 11:	0.427	2.00	2.50	3.00
Obs 12:	0.695	2.00	2.50	6.00
Obs 13:	0.839	2.00	2.50	9.00
Obs 14:	0.916	2.00	2.50	12.0
Obs 15:	0.958	2.00	2.50	15.0
Obs 16:	0.979	2.00	2.50	18.0
Obs 17:	0.989	2.00	2.50	21.0
Obs 18:	0.995	2.00	2.50	24.0
Obs 19:	0.998	2.00	2.50	27.0
Obs 20:	0.999	2.00	2.50	30.0
Obs 21:	0.358	2.00	3.00	3.00
Obs 22:	0.584	2.00	3.00	6.00
Obs 23:	0.730	2.00	3.00	9.00
Obs 24:	0.826	2.00	3.00	12.0
Obs 25:	0.889	2.00	3.00	15.0
Obs 26:	0.930	2.00	3.00	18.0
Obs 27:	0.956	2.00	3.00	21.0
Obs 28:	0.973	2.00	3.00	24.0
Obs 29:	0.983	2.00	3.00	27.0
Obs 30:	0.990	2.00	3.00	30.0
Obs 31:	0.762	3.00	2.00	3.00
Obs 32:	0.980	3.00	2.00	6.00
Obs 33:	0.998	3.00	2.00	9.00
Obs 34:	1.000	3.00	2.00	12.0
Obs 35:	1.000	3.00	2.00	15.0
Obs 36:	1.000	3.00	2.00	18.0
Obs 37:	1.000	3.00	2.00	21.0
Obs 38:	1.000	3.00	2.00	24.0
Obs 39:	1.000	3.00	2.00	27.0
Obs 40:	1.000	3.00	2.00	30.0
Obs 41:	0.631	3.00	2.50	3.00
Obs 42:	0.918	3.00	2.50	6.00
Obs 43:	0.983	3.00	2.50	9.00
Obs 44:	0.997	3.00	2.50	12.0
Obs 45:	0.999	3.00	2.50	15.0
Obs 46:	1.000	3.00	2.50	18.0
Obs 47:	1.000	3.00	2.50	21.0
Obs 48:	1.000	3.00	2.50	24.0
Obs 49:	1.000	3.00	2.50	27.0
Obs 50:	1.000	3.00	2.50	30.0
Obs 51:	0.531	3.00	3.00	3.00
Obs 52:	0.829	3.00	3.00	6.00
Obs 53:	0.940	3.00	3.00	9.00
Obs 54:	0.980	3.00	3.00	12.0
Obs 55:	0.993	3.00	3.00	15.0
Obs 56:	0.998	3.00	3.00	18.0
Obs 57:	0.999	3.00	3.00	21.0
Obs 58:	1.000	3.00	3.00	24.0

Variable:	PowerOfTe	muDA	stdDbar	n
Obs 59:	1.000	3.00	3.00	27.0
Obs 60:	1.000	3.00	3.00	30.0
Obs 61:	0.908	4.00	2.00	3.00
Obs 62:	0.999	4.00	2.00	6.00
Obs 63:	1.000	4.00	2.00	9.00
Obs 64:	1.000	4.00	2.00	12.0
Obs 65:	1.000	4.00	2.00	15.0
Obs 66:	1.00	4.00	2.00	18.0
Obs 67:	1.00	4.00	2.00	21.0
Obs 68:	1.00	4.00	2.00	24.0
Obs 69:	1.00	4.00	2.00	27.0
Obs 70:	1.00	4.00	2.00	30.0
Obs 71:	0.799	4.00	2.50	3.00
Obs 72:	0.988	4.00	2.50	6.00
Obs 73:	0.999	4.00	2.50	9.00
Obs 74:	1.000	4.00	2.50	12.0
Obs 75:	1.000	4.00	2.50	15.0
Obs 76:	1.000	4.00	2.50	18.0
Obs 77:	1.000	4.00	2.50	21.0
Obs 78:	1.000	4.00	2.50	24.0
Obs 79:	1.000	4.00	2.50	27.0
Obs 80:	1.00	4.00	2.50	30.0
Obs 81:	0.693	4.00	3.00	3.00
Obs 82:	0.954	4.00	3.00	6.00
Obs 83:	0.994	4.00	3.00	9.00
Obs 84:	0.999	4.00	3.00	12.0
Obs 85:	1.000	4.00	3.00	15.0
Obs 86:	1.000	4.00	3.00	18.0
Obs 87:	1.000	4.00	3.00	21.0
Obs 88:	1.000	4.00	3.00	24.0
Obs 89:	1.000	4.00	3.00	27.0
Obs 90:	1.000	4.00	3.00	30.0

Sample size for difference between two population means

This second computer program was used to determine a range of sample sizes for the difference between two populations means which would meet a significance level of $\alpha = 0.1$ and a power of the test of $1-\beta = 0.9$. The hypothesized mean delta was allowed to vary from 2 to 4 points and the standard deviation was allowed to vary from 2 to 3. The results follow the program.

```
$ * FILE: rsmdss.pwr (28)
$ *--------------------------------------------------;
$ TEST Two Sample Right-Sided t-Test ;
$ *--------------------------------------------------;
$ * This is a Test About the Difference Between Two ;
$ * Population Means From Normal Populations With
$ * UNKNOWN Variances that are presumed TO BE EQUAL;
$ *---------------------------------------------------;
$  Type = t, right; df=m+n-2;  Alpha = siglev;
$  H0nc = (delta0-delta0)/sqrt(pooledv*((1/m)+(1/n)));
$  H1nc = (delta1-delta0)/sqrt(pooledv*((1/m)+(1/n)));
$ *---------------------------------------------------;
$ * Below we declare a variable to place the Power;
$ * of the test into and retain this variable and;
$ * the one or more alternate values of mu so we;
$ * can plot the Power Function;
$ *----------------------------------------------------;
$  PwrVar = PowerOfTest; retain
PowerOfTest,delta1,varx,vary,m,n;
$ *----------------------------------------------------;
$ prompt delta0, delta1, siglev, xbar, ybar, varx, vary, m,
n;
$ define
pooledv=(((m-1)/(m+n-2)*varx)+((n-1)/(m+n-2)*vary));
$ run;

Enter delta0, delta1, siglev, xbar, ybar, varx, vary, m, n :
0,2,.1,30,11,4,4,4(2)30,4(2)30
```

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 1:	0.513	2.00	4.00	4.00	4.00	4.00
Obs 2:	0.574	2.00	4.00	4.00	4.00	6.00
Obs 3:	0.611	2.00	4.00	4.00	4.00	8.00
Obs 4:	0.637	2.00	4.00	4.00	4.00	10.0
Obs 5:	0.655	2.00	4.00	4.00	4.00	12.0
Obs 6:	0.669	2.00	4.00	4.00	4.00	14.0
Obs 7:	0.679	2.00	4.00	4.00	4.00	16.0
Obs 8:	0.688	2.00	4.00	4.00	4.00	18.0
Obs 9:	0.695	2.00	4.00	4.00	4.00	20.0
Obs 10:	0.701	2.00	4.00	4.00	4.00	22.0
Obs 11:	0.706	2.00	4.00	4.00	4.00	24.0
Obs 12:	0.710	2.00	4.00	4.00	4.00	26.0
Obs 13:	0.713	2.00	4.00	4.00	4.00	28.0
Obs 14:	0.717	2.00	4.00	4.00	4.00	30.0
Obs 15:	0.574	2.00	4.00	4.00	6.00	4.00
Obs 16:	0.647	2.00	4.00	4.00	6.00	6.00
Obs 17:	0.693	2.00	4.00	4.00	6.00	8.00
Obs 18:	0.725	2.00	4.00	4.00	6.00	10.0
Obs 19:	0.747	2.00	4.00	4.00	6.00	12.0
Obs 20:	0.764	2.00	4.00	4.00	6.00	14.0
Obs 21:	0.777	2.00	4.00	4.00	6.00	16.0
Obs 22:	0.788	2.00	4.00	4.00	6.00	18.0
Obs 23:	0.797	2.00	4.00	4.00	6.00	20.0
Obs 24:	0.804	2.00	4.00	4.00	6.00	22.0

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 25:	0.810	2.00	4.00	4.00	6.00	24.0
Obs 26:	0.815	2.00	4.00	4.00	6.00	26.0
Obs 27:	0.819	2.00	4.00	4.00	6.00	28.0
Obs 28:	0.823	2.00	4.00	4.00	6.00	30.0
Obs 29:	0.611	2.00	4.00	4.00	8.00	4.00
Obs 30:	0.693	2.00	4.00	4.00	8.00	6.00
Obs 31:	0.745	2.00	4.00	4.00	8.00	8.00
Obs 32:	0.780	2.00	4.00	4.00	8.00	10.0
Obs 33:	0.805	2.00	4.00	4.00	8.00	12.0
Obs 34:	0.823	2.00	4.00	4.00	8.00	14.0
Obs 35:	0.837	2.00	4.00	4.00	8.00	16.0
Obs 36:	0.849	2.00	4.00	4.00	8.00	18.0
Obs 37:	0.858	2.00	4.00	4.00	8.00	20.0
Obs 38:	0.865	2.00	4.00	4.00	8.00	22.0
Obs 39:	0.872	2.00	4.00	4.00	8.00	24.0
Obs 40:	0.877	2.00	4.00	4.00	8.00	26.0
Obs 41:	0.881	2.00	4.00	4.00	8.00	28.0
Obs 42:	0.885	2.00	4.00	4.00	8.00	30.0
Obs 43:	0.637	2.00	4.00	4.00	10.0	4.00
Obs 44:	0.725	2.00	4.00	4.00	10.0	6.00
Obs 45:	0.780	2.00	4.00	4.00	10.0	8.00
Obs 46:	0.817	2.00	4.00	4.00	10.0	10.0
Obs 47:	0.843	2.00	4.00	4.00	10.0	12.0
Obs 48:	0.862	2.00	4.00	4.00	10.0	14.0
Obs 49:	0.876	2.00	4.00	4.00	10.0	16.0
Obs 50:	0.887	2.00	4.00	4.00	10.0	18.0
Obs 51:	0.897	2.00	4.00	4.00	10.0	20.0
Obs 52:	0.904	2.00	4.00	4.00	10.0	22.0
Obs 53:	0.910	2.00	4.00	4.00	10.0	24.0
Obs 54:	0.915	2.00	4.00	4.00	10.0	26.0
Obs 55:	0.919	2.00	4.00	4.00	10.0	28.0
Obs 56:	0.923	2.00	4.00	4.00	10.0	30.0
Obs 57:	0.655	2.00	4.00	4.00	12.0	4.00
Obs 58:	0.747	2.00	4.00	4.00	12.0	6.00
Obs 59:	0.805	2.00	4.00	4.00	12.0	8.00
Obs 60:	0.843	2.00	4.00	4.00	12.0	10.0
Obs 61:	0.869	2.00	4.00	4.00	12.0	12.0
Obs 62:	0.888	2.00	4.00	4.00	12.0	14.0
Obs 63:	0.902	2.00	4.00	4.00	12.0	16.0
Obs 64:	0.913	2.00	4.00	4.00	12.0	18.0
Obs 65:	0.922	2.00	4.00	4.00	12.0	20.0
Obs 66:	0.929	2.00	4.00	4.00	12.0	22.0
Obs 67:	0.935	2.00	4.00	4.00	12.0	24.0
Obs 68:	0.940	2.00	4.00	4.00	12.0	26.0
Obs 69:	0.944	2.00	4.00	4.00	12.0	28.0
Obs 70:	0.947	2.00	4.00	4.00	12.0	30.0
Obs 71:	0.669	2.00	4.00	4.00	14.0	4.00
Obs 72:	0.764	2.00	4.00	4.00	14.0	6.00
Obs 73:	0.823	2.00	4.00	4.00	14.0	8.00
Obs 74:	0.862	2.00	4.00	4.00	14.0	10.0
Obs 75:	0.888	2.00	4.00	4.00	14.0	12.0
Obs 76:	0.907	2.00	4.00	4.00	14.0	14.0
Obs 77:	0.921	2.00	4.00	4.00	14.0	16.0
Obs 78:	0.931	2.00	4.00	4.00	14.0	18.0
Obs 79:	0.940	2.00	4.00	4.00	14.0	20.0
Obs 80:	0.946	2.00	4.00	4.00	14.0	22.0
Obs 81:	0.951	2.00	4.00	4.00	14.0	24.0
Obs 82:	0.956	2.00	4.00	4.00	14.0	26.0
Obs 83:	0.959	2.00	4.00	4.00	14.0	28.0
Obs 84:	0.962	2.00	4.00	4.00	14.0	30.0
Obs 85:	0.679	2.00	4.00	4.00	16.0	4.00

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 86:	0.777	2.00	4.00	4.00	16.0	6.00
Obs 87:	0.837	2.00	4.00	4.00	16.0	8.00
Obs 88:	0.876	2.00	4.00	4.00	16.0	10.0
Obs 89:	0.902	2.00	4.00	4.00	16.0	12.0
Obs 90:	0.921	2.00	4.00	4.00	16.0	14.0
Obs 91:	0.934	2.00	4.00	4.00	16.0	16.0
Obs 92:	0.944	2.00	4.00	4.00	16.0	18.0
Obs 93:	0.952	2.00	4.00	4.00	16.0	20.0
Obs 94:	0.958	2.00	4.00	4.00	16.0	22.0
Obs 95:	0.963	2.00	4.00	4.00	16.0	24.0
Obs 96:	0.967	2.00	4.00	4.00	16.0	26.0
Obs 97:	0.970	2.00	4.00	4.00	16.0	28.0
Obs 98:	0.972	2.00	4.00	4.00	16.0	30.0
Obs 99:	0.688	2.00	4.00	4.00	18.0	4.00
Obs 100:	0.788	2.00	4.00	4.00	18.0	6.00
Obs 101:	0.849	2.00	4.00	4.00	18.0	8.00
Obs 102:	0.887	2.00	4.00	4.00	18.0	10.0
Obs 103:	0.913	2.00	4.00	4.00	18.0	12.0
Obs 104:	0.931	2.00	4.00	4.00	18.0	14.0
Obs 105:	0.944	2.00	4.00	4.00	18.0	16.0
Obs 106:	0.954	2.00	4.00	4.00	18.0	18.0
Obs 107:	0.961	2.00	4.00	4.00	18.0	20.0
Obs 108:	0.966	2.00	4.00	4.00	18.0	22.0
Obs 109:	0.971	2.00	4.00	4.00	18.0	24.0
Obs 110:	0.974	2.00	4.00	4.00	18.0	26.0
Obs 111:	0.977	2.00	4.00	4.00	18.0	28.0
Obs 112:	0.979	2.00	4.00	4.00	18.0	30.0
Obs 113:	0.695	2.00	4.00	4.00	20.0	4.00
Obs 114:	0.797	2.00	4.00	4.00	20.0	6.00
Obs 115:	0.858	2.00	4.00	4.00	20.0	8.00
Obs 116:	0.897	2.00	4.00	4.00	20.0	10.0
Obs 117:	0.922	2.00	4.00	4.00	20.0	12.0
Obs 118:	0.940	2.00	4.00	4.00	20.0	14.0
Obs 119:	0.952	2.00	4.00	4.00	20.0	16.0
Obs 120:	0.961	2.00	4.00	4.00	20.0	18.0
Obs 121:	0.968	2.00	4.00	4.00	20.0	20.0
Obs 41:	0.666	2.00	6.25	6.25	6.00	22.0
Obs 42:	0.672	2.00	6.25	6.25	6.00	24.0
Obs 43:	0.677	2.00	6.25	6.25	6.00	26.0
Obs 44:	0.682	2.00	6.25	6.25	6.00	28.0
Obs 45:	0.686	2.00	6.25	6.25	6.00	30.0
Obs 46:	0.374	2.00	6.25	6.25	8.00	2.00
Obs 47:	0.488	2.00	6.25	6.25	8.00	4.00
Obs 48:	0.559	2.00	6.25	6.25	8.00	6.00
Obs 49:	0.607	2.00	6.25	6.25	8.00	8.00
Obs 50:	0.641	2.00	6.25	6.25	8.00	10.0
Obs 51:	0.667	2.00	6.25	6.25	8.00	12.0
Obs 52:	0.686	2.00	6.25	6.25	8.00	14.0
Obs 53:	0.702	2.00	6.25	6.25	8.00	16.0
Obs 54:	0.715	2.00	6.25	6.25	8.00	18.0
Obs 55:	0.726	2.00	6.25	6.25	8.00	20.0
Obs 56:	0.735	2.00	6.25	6.25	8.00	22.0
Obs 57:	0.742	2.00	6.25	6.25	8.00	24.0
Obs 58:	0.749	2.00	6.25	6.25	8.00	26.0
Obs 59:	0.755	2.00	6.25	6.25	8.00	28.0
Obs 60:	0.760	2.00	6.25	6.25	8.00	30.0
Obs 61:	0.385	2.00	6.25	6.25	10.0	2.00
Obs 62:	0.509	2.00	6.25	6.25	10.0	4.00
Obs 63:	0.588	2.00	6.25	6.25	10.0	6.00
Obs 64:	0.641	2.00	6.25	6.25	10.0	8.00
Obs 65:	0.679	2.00	6.25	6.25	10.0	10.0

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 66:	0.708	2.00	6.25	6.25	10.0	12.0
Obs 67:	0.730	2.00	6.25	6.25	10.0	14.0
Obs 68:	0.748	2.00	6.25	6.25	10.0	16.0
Obs 69:	0.763	2.00	6.25	6.25	10.0	18.0
Obs 70:	0.774	2.00	6.25	6.25	10.0	20.0
Obs 71:	0.784	2.00	6.25	6.25	10.0	22.0
Obs 72:	0.793	2.00	6.25	6.25	10.0	24.0
Obs 73:	0.800	2.00	6.25	6.25	10.0	26.0
Obs 74:	0.806	2.00	6.25	6.25	10.0	28.0
Obs 75:	0.812	2.00	6.25	6.25	10.0	30.0
Obs 76:	0.393	2.00	6.25	6.25	12.0	2.00
Obs 77:	0.525	2.00	6.25	6.25	12.0	4.00
Obs 78:	0.609	2.00	6.25	6.25	12.0	6.00
Obs 79:	0.667	2.00	6.25	6.25	12.0	8.00
Obs 80:	0.708	2.00	6.25	6.25	12.0	10.0
Obs 81:	0.739	2.00	6.25	6.25	12.0	12.0
Obs 82:	0.763	2.00	6.25	6.25	12.0	14.0
Obs 83:	0.782	2.00	6.25	6.25	12.0	16.0
Obs 84:	0.798	2.00	6.25	6.25	12.0	18.0
Obs 85:	0.810	2.00	6.25	6.25	12.0	20.0
Obs 86:	0.821	2.00	6.25	6.25	12.0	22.0
Obs 87:	0.830	2.00	6.25	6.25	12.0	24.0
Obs 88:	0.838	2.00	6.25	6.25	12.0	26.0
Obs 89:	0.844	2.00	6.25	6.25	12.0	28.0
Obs 90:	0.850	2.00	6.25	6.25	12.0	30.0
Obs 91:	0.400	2.00	6.25	6.25	14.0	2.00
Obs 92:	0.537	2.00	6.25	6.25	14.0	4.00
Obs 93:	0.626	2.00	6.25	6.25	14.0	6.00
Obs 94:	0.686	2.00	6.25	6.25	14.0	8.00
Obs 95:	0.730	2.00	6.25	6.25	14.0	10.0
Obs 96:	0.763	2.00	6.25	6.25	14.0	12.0
Obs 97:	0.788	2.00	6.25	6.25	14.0	14.0
Obs 98:	0.808	2.00	6.25	6.25	14.0	16.0
Obs 99:	0.824	2.00	6.25	6.25	14.0	18.0
Obs 100:	0.838	2.00	6.25	6.25	14.0	20.0
Obs 101:	0.848	2.00	6.25	6.25	14.0	22.0
Obs 102:	0.858	2.00	6.25	6.25	14.0	24.0
Obs 103:	0.866	2.00	6.25	6.25	14.0	26.0
Obs 104:	0.872	2.00	6.25	6.25	14.0	28.0
Obs 105:	0.878	2.00	6.25	6.25	14.0	30.0
Obs 106:	0.404	2.00	6.25	6.25	16.0	2.00
Obs 107:	0.546	2.00	6.25	6.25	16.0	4.00
Obs 108:	0.639	2.00	6.25	6.25	16.0	6.00
Obs 109:	0.702	2.00	6.25	6.25	16.0	8.00
Obs 110:	0.748	2.00	6.25	6.25	16.0	10.0
Obs 111:	0.782	2.00	6.25	6.25	16.0	12.0
Obs 112:	0.808	2.00	6.25	6.25	16.0	14.0
Obs 113:	0.829	2.00	6.25	6.25	16.0	16.0
Obs 114:	0.845	2.00	6.25	6.25	16.0	18.0
Obs 115:	0.859	2.00	6.25	6.25	16.0	20.0
Obs 116:	0.870	2.00	6.25	6.25	16.0	22.0
Obs 117:	0.879	2.00	6.25	6.25	16.0	24.0
Obs 118:	0.887	2.00	6.25	6.25	16.0	26.0
Obs 119:	0.894	2.00	6.25	6.25	16.0	28.0
Obs 120:	0.899	2.00	6.25	6.25	16.0	30.0
Obs 121:	0.408	2.00	6.25	6.25	18.0	2.00
Obs 122:	0.554	2.00	6.25	6.25	18.0	4.00
Obs 123:	0.649	2.00	6.25	6.25	18.0	6.00
Obs 124:	0.715	2.00	6.25	6.25	18.0	8.00
Obs 125:	0.763	2.00	6.25	6.25	18.0	10.0
Obs 126:	0.798	2.00	6.25	6.25	18.0	12.0

Variable:		PowerOfTe	delta1	varx	vary	m	n
Obs	127:	0.824	2.00	6.25	6.25	18.0	14.0
Obs	128:	0.845	2.00	6.25	6.25	18.0	16.0
Obs	129:	0.862	2.00	6.25	6.25	18.0	18.0
Obs	130:	0.875	2.00	6.25	6.25	18.0	20.0
Obs	131:	0.886	2.00	6.25	6.25	18.0	22.0
Obs	132:	0.896	2.00	6.25	6.25	18.0	24.0
Obs	133:	0.903	2.00	6.25	6.25	18.0	26.0
Obs	134:	0.910	2.00	6.25	6.25	18.0	28.0
Obs	135:	0.916	2.00	6.25	6.25	18.0	30.0
Obs	136:	0.411	2.00	6.25	6.25	20.0	2.00
Obs	137:	0.560	2.00	6.25	6.25	20.0	4.00
Obs	138:	0.658	2.00	6.25	6.25	20.0	6.00
Obs	139:	0.726	2.00	6.25	6.25	20.0	8.00
Obs	140:	0.774	2.00	6.25	6.25	20.0	10.0
Obs	141:	0.810	2.00	6.25	6.25	20.0	12.0
Obs	142:	0.838	2.00	6.25	6.25	20.0	14.0
Obs	143:	0.859	2.00	6.25	6.25	20.0	16.0
Obs	144:	0.875	2.00	6.25	6.25	20.0	18.0
Obs	145:	0.889	2.00	6.25	6.25	20.0	20.0
Obs	146:	0.900	2.00	6.25	6.25	20.0	22.0
Obs	147:	0.909	2.00	6.25	6.25	20.0	24.0
Obs	148:	0.917	2.00	6.25	6.25	20.0	26.0
Obs	149:	0.923	2.00	6.25	6.25	20.0	28.0
Obs	150:	0.929	2.00	6.25	6.25	20.0	30.0
Obs	151:	0.413	2.00	6.25	6.25	22.0	2.00
Obs	152:	0.565	2.00	6.25	6.25	22.0	4.00
Obs	153:	0.666	2.00	6.25	6.25	22.0	6.00
Obs	154:	0.735	2.00	6.25	6.25	22.0	8.00
Obs	155:	0.784	2.00	6.25	6.25	22.0	10.0
Obs	156:	0.821	2.00	6.25	6.25	22.0	12.0
Obs	157:	0.848	2.00	6.25	6.25	22.0	14.0
Obs	158:	0.870	2.00	6.25	6.25	22.0	16.0
Obs	159:	0.886	2.00	6.25	6.25	22.0	18.0
Obs	160:	0.900	2.00	6.25	6.25	22.0	20.0
Obs	161:	0.911	2.00	6.25	6.25	22.0	22.0
Obs	162:	0.920	2.00	6.25	6.25	22.0	24.0
Obs	163:	0.927	2.00	6.25	6.25	22.0	26.0
Obs	164:	0.933	2.00	6.25	6.25	22.0	28.0
Obs	165:	0.939	2.00	6.25	6.25	22.0	30.0
Obs	166:	0.416	2.00	6.25	6.25	24.0	2.00
Obs	167:	0.570	2.00	6.25	6.25	24.0	4.00
Obs	168:	0.672	2.00	6.25	6.25	24.0	6.00
Obs	169:	0.742	2.00	6.25	6.25	24.0	8.00
Obs	170:	0.793	2.00	6.25	6.25	24.0	10.0
Obs	171:	0.830	2.00	6.25	6.25	24.0	12.0
Obs	172:	0.858	2.00	6.25	6.25	24.0	14.0
Obs	173:	0.879	2.00	6.25	6.25	24.0	16.0
Obs	174:	0.896	2.00	6.25	6.25	24.0	18.0
Obs	175:	0.909	2.00	6.25	6.25	24.0	20.0
Obs	176:	0.920	2.00	6.25	6.25	24.0	22.0
Obs	177:	0.929	2.00	6.25	6.25	24.0	24.0
Obs	178:	0.936	2.00	6.25	6.25	24.0	26.0
Obs	179:	0.942	2.00	6.25	6.25	24.0	28.0
Obs	180:	0.947	2.00	6.25	6.25	24.0	30.0
Obs	181:	0.417	2.00	6.25	6.25	26.0	2.00

```
Enter delta0, delta1, siglev, xbar, ybar, varx, vary, m, n :
0,2,.1,30,11,9,9,2(2)30,2(2)30
```

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 1:	0.228	2.00	9.00	9.00	2.00	2.00
Obs 2:	0.277	2.00	9.00	9.00	2.00	4.00
Obs 3:	0.301	2.00	9.00	9.00	2.00	6.00
Obs 4:	0.315	2.00	9.00	9.00	2.00	8.00
Obs 5:	0.324	2.00	9.00	9.00	2.00	10.0
Obs 6:	0.330	2.00	9.00	9.00	2.00	12.0
Obs 7:	0.335	2.00	9.00	9.00	2.00	14.0
Obs 8:	0.339	2.00	9.00	9.00	2.00	16.0
Obs 9:	0.342	2.00	9.00	9.00	2.00	18.0
Obs 10:	0.344	2.00	9.00	9.00	2.00	20.0
Obs 11:	0.346	2.00	9.00	9.00	2.00	22.0
Obs 12:	0.348	2.00	9.00	9.00	2.00	24.0
Obs 13:	0.349	2.00	9.00	9.00	2.00	26.0
Obs 14:	0.350	2.00	9.00	9.00	2.00	28.0
Obs 15:	0.352	2.00	9.00	9.00	2.00	30.0
Obs 16:	0.277	2.00	9.00	9.00	4.00	2.00
Obs 17:	0.343	2.00	9.00	9.00	4.00	4.00
Obs 18:	0.381	2.00	9.00	9.00	4.00	6.00
Obs 19:	0.406	2.00	9.00	9.00	4.00	8.00
Obs 20:	0.423	2.00	9.00	9.00	4.00	10.0
Obs 21:	0.436	2.00	9.00	9.00	4.00	12.0
Obs 22:	0.446	2.00	9.00	9.00	4.00	14.0
Obs 23:	0.454	2.00	9.00	9.00	4.00	16.0
Obs 24:	0.460	2.00	9.00	9.00	4.00	18.0
Obs 25:	0.465	2.00	9.00	9.00	4.00	20.0
Obs 26:	0.470	2.00	9.00	9.00	4.00	22.0
Obs 27:	0.473	2.00	9.00	9.00	4.00	24.0
Obs 28:	0.477	2.00	9.00	9.00	4.00	26.0
Obs 29:	0.479	2.00	9.00	9.00	4.00	28.0
Obs 30:	0.482	2.00	9.00	9.00	4.00	30.0
Obs 31:	0.301	2.00	9.00	9.00	6.00	2.00
Obs 32:	0.381	2.00	9.00	9.00	6.00	4.00
Obs 33:	0.431	2.00	9.00	9.00	6.00	6.00
Obs 34:	0.464	2.00	9.00	9.00	6.00	8.00
Obs 35:	0.488	2.00	9.00	9.00	6.00	10.0
Obs 36:	0.507	2.00	9.00	9.00	6.00	12.0
Obs 37:	0.521	2.00	9.00	9.00	6.00	14.0
Obs 38:	0.533	2.00	9.00	9.00	6.00	16.0
Obs 39:	0.542	2.00	9.00	9.00	6.00	18.0
Obs 40:	0.550	2.00	9.00	9.00	6.00	20.0
Obs 41:	0.557	2.00	9.00	9.00	6.00	22.0
Obs 42:	0.563	2.00	9.00	9.00	6.00	24.0
Obs 43:	0.568	2.00	9.00	9.00	6.00	26.0
Obs 44:	0.572	2.00	9.00	9.00	6.00	28.0
Obs 45:	0.576	2.00	9.00	9.00	6.00	30.0
Obs 46:	0.315	2.00	9.00	9.00	8.00	2.00
Obs 47:	0.406	2.00	9.00	9.00	8.00	4.00
Obs 48:	0.464	2.00	9.00	9.00	8.00	6.00
Obs 49:	0.505	2.00	9.00	9.00	8.00	8.00
Obs 50:	0.535	2.00	9.00	9.00	8.00	10.0
Obs 51:	0.558	2.00	9.00	9.00	8.00	12.0
Obs 52:	0.576	2.00	9.00	9.00	8.00	14.0
Obs 53:	0.591	2.00	9.00	9.00	8.00	16.0
Obs 54:	0.603	2.00	9.00	9.00	8.00	18.0
Obs 55:	0.613	2.00	9.00	9.00	8.00	20.0
Obs 56:	0.621	2.00	9.00	9.00	8.00	22.0
Obs 57:	0.629	2.00	9.00	9.00	8.00	24.0
Obs 58:	0.635	2.00	9.00	9.00	8.00	26.0

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 59:	0.641	2.00	9.00	9.00	8.00	28.0
Obs 60:	0.646	2.00	9.00	9.00	8.00	30.0
Obs 61:	0.324	2.00	9.00	9.00	10.0	2.00
Obs 62:	0.423	2.00	9.00	9.00	10.0	4.00
Obs 63:	0.488	2.00	9.00	9.00	10.0	6.00
Obs 64:	0.535	2.00	9.00	9.00	10.0	8.00
Obs 65:	0.569	2.00	9.00	9.00	10.0	10.0
Obs 66:	0.596	2.00	9.00	9.00	10.0	12.0
Obs 67:	0.617	2.00	9.00	9.00	10.0	14.0
Obs 68:	0.634	2.00	9.00	9.00	10.0	16.0
Obs 69:	0.649	2.00	9.00	9.00	10.0	18.0
Obs 70:	0.661	2.00	9.00	9.00	10.0	20.0
Obs 71:	0.671	2.00	9.00	9.00	10.0	22.0
Obs 72:	0.680	2.00	9.00	9.00	10.0	24.0
Obs 73:	0.687	2.00	9.00	9.00	10.0	26.0
Obs 74:	0.694	2.00	9.00	9.00	10.0	28.0
Obs 75:	0.700	2.00	9.00	9.00	10.0	30.0
Obs 76:	0.330	2.00	9.00	9.00	12.0	2.00
Obs 77:	0.436	2.00	9.00	9.00	12.0	4.00
Obs 78:	0.507	2.00	9.00	9.00	12.0	6.00
Obs 79:	0.558	2.00	9.00	9.00	12.0	8.00
Obs 80:	0.596	2.00	9.00	9.00	12.0	10.0
Obs 81:	0.626	2.00	9.00	9.00	12.0	12.0
Obs 82:	0.649	2.00	9.00	9.00	12.0	14.0
Obs 83:	0.669	2.00	9.00	9.00	12.0	16.0
Obs 84:	0.685	2.00	9.00	9.00	12.0	18.0
Obs 85:	0.698	2.00	9.00	9.00	12.0	20.0
Obs 86:	0.710	2.00	9.00	9.00	12.0	22.0
Obs 87:	0.719	2.00	9.00	9.00	12.0	24.0
Obs 88:	0.728	2.00	9.00	9.00	12.0	26.0
Obs 89:	0.736	2.00	9.00	9.00	12.0	28.0
Obs 90:	0.742	2.00	9.00	9.00	12.0	30.0
Obs 91:	0.335	2.00	9.00	9.00	14.0	2.00
Obs 92:	0.446	2.00	9.00	9.00	14.0	4.00
Obs 93:	0.521	2.00	9.00	9.00	14.0	6.00
Obs 94:	0.576	2.00	9.00	9.00	14.0	8.00
Obs 95:	0.617	2.00	9.00	9.00	14.0	10.0
Obs 96:	0.649	2.00	9.00	9.00	14.0	12.0
Obs 97:	0.675	2.00	9.00	9.00	14.0	14.0
Obs 98:	0.696	2.00	9.00	9.00	14.0	16.0
Obs 99:	0.713	2.00	9.00	9.00	14.0	18.0
Obs 100:	0.728	2.00	9.00	9.00	14.0	20.0
Obs 101:	0.740	2.00	9.00	9.00	14.0	22.0
Obs 102:	0.751	2.00	9.00	9.00	14.0	24.0
Obs 103:	0.760	2.00	9.00	9.00	14.0	26.0
Obs 104:	0.769	2.00	9.00	9.00	14.0	28.0
Obs 105:	0.776	2.00	9.00	9.00	14.0	30.0
Obs 106:	0.339	2.00	9.00	9.00	16.0	2.00
Obs 107:	0.454	2.00	9.00	9.00	16.0	4.00
Obs 108:	0.533	2.00	9.00	9.00	16.0	6.00
Obs 109:	0.591	2.00	9.00	9.00	16.0	8.00
Obs 110:	0.634	2.00	9.00	9.00	16.0	10.0
Obs 111:	0.669	2.00	9.00	9.00	16.0	12.0
Obs 112:	0.696	2.00	9.00	9.00	16.0	14.0
Obs 113:	0.718	2.00	9.00	9.00	16.0	16.0
Obs 114:	0.737	2.00	9.00	9.00	16.0	18.0
Obs 115:	0.752	2.00	9.00	9.00	16.0	20.0
Obs 116:	0.766	2.00	9.00	9.00	16.0	22.0
Obs 117:	0.777	2.00	9.00	9.00	16.0	24.0
Obs 118:	0.787	2.00	9.00	9.00	16.0	26.0
Obs 119:	0.795	2.00	9.00	9.00	16.0	28.0

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 120:	0.803	2.00	9.00	9.00	16.0	30.0
Obs 121:	0.342	2.00	9.00	9.00	18.0	2.00
Obs 122:	0.460	2.00	9.00	9.00	18.0	4.00
Obs 123:	0.542	2.00	9.00	9.00	18.0	6.00
Obs 124:	0.603	2.00	9.00	9.00	18.0	8.00
Obs 125:	0.649	2.00	9.00	9.00	18.0	10.0
Obs 126:	0.685	2.00	9.00	9.00	18.0	12.0
Obs 127:	0.713	2.00	9.00	9.00	18.0	14.0
Obs 128:	0.737	2.00	9.00	9.00	18.0	16.0
Obs 129:	0.756	2.00	9.00	9.00	18.0	18.0
Obs 130:	0.772	2.00	9.00	9.00	18.0	20.0
Obs 131:	0.786	2.00	9.00	9.00	18.0	22.0
Obs 132:	0.798	2.00	9.00	9.00	18.0	24.0
Obs 133:	0.808	2.00	9.00	9.00	18.0	26.0
Obs 134:	0.817	2.00	9.00	9.00	18.0	28.0
Obs 135:	0.825	2.00	9.00	9.00	18.0	30.0
Obs 136:	0.344	2.00	9.00	9.00	20.0	2.00
Obs 137:	0.465	2.00	9.00	9.00	20.0	4.00
Obs 138:	0.550	2.00	9.00	9.00	20.0	6.00
Obs 139:	0.613	2.00	9.00	9.00	20.0	8.00
Obs 140:	0.661	2.00	9.00	9.00	20.0	10.0
Obs 141:	0.698	2.00	9.00	9.00	20.0	12.0
Obs 142:	0.728	2.00	9.00	9.00	20.0	14.0
Obs 143:	0.752	2.00	9.00	9.00	20.0	16.0
Obs 144:	0.772	2.00	9.00	9.00	20.0	18.0
Obs 145:	0.789	2.00	9.00	9.00	20.0	20.0
Obs 146:	0.803	2.00	9.00	9.00	20.0	22.0
Obs 147:	0.816	2.00	9.00	9.00	20.0	24.0
Obs 148:	0.826	2.00	9.00	9.00	20.0	26.0
Obs 149:	0.835	2.00	9.00	9.00	20.0	28.0
Obs 150:	0.843	2.00	9.00	9.00	20.0	30.0
Obs 151:	0.346	2.00	9.00	9.00	22.0	2.00
Obs 152:	0.470	2.00	9.00	9.00	22.0	4.00
Obs 153:	0.557	2.00	9.00	9.00	22.0	6.00
Obs 154:	0.621	2.00	9.00	9.00	22.0	8.00
Obs 155:	0.671	2.00	9.00	9.00	22.0	10.0
Obs 156:	0.710	2.00	9.00	9.00	22.0	12.0
Obs 157:	0.740	2.00	9.00	9.00	22.0	14.0
Obs 158:	0.766	2.00	9.00	9.00	22.0	16.0
Obs 159:	0.786	2.00	9.00	9.00	22.0	18.0
Obs 160:	0.803	2.00	9.00	9.00	22.0	20.0
Obs 161:	0.818	2.00	9.00	9.00	22.0	22.0
Obs 162:	0.830	2.00	9.00	9.00	22.0	24.0
Obs 163:	0.841	2.00	9.00	9.00	22.0	26.0
Obs 164:	0.850	2.00	9.00	9.00	22.0	28.0
Obs 165:	0.859	2.00	9.00	9.00	22.0	30.0
Obs 166:	0.348	2.00	9.00	9.00	24.0	2.00
Obs 167:	0.473	2.00	9.00	9.00	24.0	4.00
Obs 168:	0.563	2.00	9.00	9.00	24.0	6.00
Obs 169:	0.629	2.00	9.00	9.00	24.0	8.00
Obs 170:	0.680	2.00	9.00	9.00	24.0	10.0
Obs 171:	0.719	2.00	9.00	9.00	24.0	12.0
Obs 172:	0.751	2.00	9.00	9.00	24.0	14.0
Obs 173:	0.777	2.00	9.00	9.00	24.0	16.0
Obs 174:	0.798	2.00	9.00	9.00	24.0	18.0
Obs 175:	0.816	2.00	9.00	9.00	24.0	20.0
Obs 176:	0.830	2.00	9.00	9.00	24.0	22.0
Obs 177:	0.843	2.00	9.00	9.00	24.0	24.0
Obs 178:	0.854	2.00	9.00	9.00	24.0	26.0
Obs 179:	0.863	2.00	9.00	9.00	24.0	28.0
Obs 180:	0.871	2.00	9.00	9.00	24.0	30.0

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 181:	0.349	2.00	9.00	9.00	26.0	2.00
Obs 182:	0.477	2.00	9.00	9.00	26.0	4.00
Obs 183:	0.568	2.00	9.00	9.00	26.0	6.00
Obs 184:	0.635	2.00	9.00	9.00	26.0	8.00
Obs 185:	0.687	2.00	9.00	9.00	26.0	10.0
Obs 186:	0.728	2.00	9.00	9.00	26.0	12.0
Obs 187:	0.760	2.00	9.00	9.00	26.0	14.0
Obs 188:	0.787	2.00	9.00	9.00	26.0	16.0
Obs 189:	0.808	2.00	9.00	9.00	26.0	18.0
Obs 190:	0.826	2.00	9.00	9.00	26.0	20.0
Obs 191:	0.841	2.00	9.00	9.00	26.0	22.0
Obs 192:	0.854	2.00	9.00	9.00	26.0	24.0
Obs 193:	0.865	2.00	9.00	9.00	26.0	26.0
Obs 194:	0.874	2.00	9.00	9.00	26.0	28.0
Obs 195:	0.882	2.00	9.00	9.00	26.0	30.0
Obs 196:	0.350	2.00	9.00	9.00	28.0	2.00
Obs 197:	0.479	2.00	9.00	9.00	28.0	4.00
Obs 198:	0.572	2.00	9.00	9.00	28.0	6.00
Obs 199:	0.641	2.00	9.00	9.00	28.0	8.00
Obs 200:	0.694	2.00	9.00	9.00	28.0	10.0
Obs 201:	0.736	2.00	9.00	9.00	28.0	12.0
Obs 202:	0.769	2.00	9.00	9.00	28.0	14.0
Obs 203:	0.795	2.00	9.00	9.00	28.0	16.0
Obs 204:	0.817	2.00	9.00	9.00	28.0	18.0
Obs 205:	0.835	2.00	9.00	9.00	28.0	20.0
Obs 206:	0.850	2.00	9.00	9.00	28.0	22.0
Obs 207:	0.863	2.00	9.00	9.00	28.0	24.0
Obs 208:	0.874	2.00	9.00	9.00	28.0	26.0
Obs 209:	0.884	2.00	9.00	9.00	28.0	28.0
Obs 210:	0.892	2.00	9.00	9.00	28.0	30.0
Obs 211:	0.352	2.00	9.00	9.00	30.0	2.00
Obs 212:	0.482	2.00	9.00	9.00	30.0	4.00
Obs 213:	0.576	2.00	9.00	9.00	30.0	6.00
Obs 214:	0.646	2.00	9.00	9.00	30.0	8.00
Obs 215:	0.700	2.00	9.00	9.00	30.0	10.0
Obs 216:	0.742	2.00	9.00	9.00	30.0	12.0
Obs 217:	0.776	2.00	9.00	9.00	30.0	14.0
Obs 218:	0.803	2.00	9.00	9.00	30.0	16.0
Obs 219:	0.825	2.00	9.00	9.00	30.0	18.0
Obs 220:	0.843	2.00	9.00	9.00	30.0	20.0
Obs 221:	0.859	2.00	9.00	9.00	30.0	22.0
Obs 222:	0.871	2.00	9.00	9.00	30.0	24.0
Obs 223:	0.882	2.00	9.00	9.00	30.0	26.0
Obs 224:	0.892	2.00	9.00	9.00	30.0	28.0
Obs 225:	0.900	2.00	9.00	9.00	30.0	30.0

```
Enter delta0, delta1, siglev, xbar, ybar, varx, vary, m, n :
0,4,.1,30,11,4,4,2(2)30,2(2)30
```

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 1:	0.609	4.00	4.00	4.00	2.00	2.00
Obs 2:	0.780	4.00	4.00	4.00	2.00	4.00
Obs 3:	0.839	4.00	4.00	4.00	2.00	6.00
Obs 4:	0.867	4.00	4.00	4.00	2.00	8.00
Obs 5:	0.883	4.00	4.00	4.00	2.00	10.0
Obs 6:	0.893	4.00	4.00	4.00	2.00	12.0
Obs 7:	0.900	4.00	4.00	4.00	2.00	14.0
Obs 8:	0.906	4.00	4.00	4.00	2.00	16.0
Obs 9:	0.910	4.00	4.00	4.00	2.00	18.0
Obs 10:	0.913	4.00	4.00	4.00	2.00	20.0

Variable:		PowerOfTe	delta1	varx	vary	m	n
Obs	11:	0.915	4.00	4.00	4.00	2.00	22.0
Obs	12:	0.918	4.00	4.00	4.00	2.00	24.0
Obs	13:	0.919	4.00	4.00	4.00	2.00	26.0
Obs	14:	0.921	4.00	4.00	4.00	2.00	28.0
Obs	15:	0.922	4.00	4.00	4.00	2.00	30.0
Obs	16:	0.780	4.00	4.00	4.00	4.00	2.00
Obs	17:	0.910	4.00	4.00	4.00	4.00	4.00
Obs	18:	0.950	4.00	4.00	4.00	4.00	6.00
Obs	19:	0.967	4.00	4.00	4.00	4.00	8.00
Obs	20:	0.976	4.00	4.00	4.00	4.00	10.0
Obs	21:	0.981	4.00	4.00	4.00	4.00	12.0
Obs	22:	0.984	4.00	4.00	4.00	4.00	14.0
Obs	23:	0.987	4.00	4.00	4.00	4.00	16.0
Obs	24:	0.988	4.00	4.00	4.00	4.00	18.0
Obs	25:	0.989	4.00	4.00	4.00	4.00	20.0
Obs	26:	0.990	4.00	4.00	4.00	4.00	22.0
Obs	27:	0.991	4.00	4.00	4.00	4.00	24.0
Obs	28:	0.991	4.00	4.00	4.00	4.00	26.0
Obs	29:	0.992	4.00	4.00	4.00	4.00	28.0
Obs	30:	0.992	4.00	4.00	4.00	4.00	30.0
Obs	31:	0.839	4.00	4.00	4.00	6.00	2.00
Obs	32:	0.950	4.00	4.00	4.00	6.00	4.00
Obs	33:	0.979	4.00	4.00	4.00	6.00	6.00
Obs	34:	0.989	4.00	4.00	4.00	6.00	8.00
Obs	35:	0.993	4.00	4.00	4.00	6.00	10.0
Obs	36:	0.995	4.00	4.00	4.00	6.00	12.0
Obs	37:	0.997	4.00	4.00	4.00	6.00	14.0
Obs	38:	0.998	4.00	4.00	4.00	6.00	16.0
Obs	39:	0.998	4.00	4.00	4.00	6.00	18.0
Obs	40:	0.998	4.00	4.00	4.00	6.00	20.0
Obs	41:	0.999	4.00	4.00	4.00	6.00	22.0
Obs	42:	0.999	4.00	4.00	4.00	6.00	24.0
Obs	43:	0.999	4.00	4.00	4.00	6.00	26.0
Obs	44:	0.999	4.00	4.00	4.00	6.00	28.0
Obs	45:	0.999	4.00	4.00	4.00	6.00	30.0
Obs	46:	0.867	4.00	4.00	4.00	8.00	2.00
Obs	47:	0.967	4.00	4.00	4.00	8.00	4.00
Obs	48:	0.989	4.00	4.00	4.00	8.00	6.00
Obs	49:	0.995	4.00	4.00	4.00	8.00	8.00
Obs	50:	0.998	4.00	4.00	4.00	8.00	10.0
Obs	51:	0.999	4.00	4.00	4.00	8.00	12.0
Obs	52:	0.999	4.00	4.00	4.00	8.00	14.0
Obs	53:	0.999	4.00	4.00	4.00	8.00	16.0
Obs	54:	1.000	4.00	4.00	4.00	8.00	18.0
Obs	55:	1.000	4.00	4.00	4.00	8.00	20.0
Obs	56:	1.000	4.00	4.00	4.00	8.00	22.0
Obs	57:	1.000	4.00	4.00	4.00	8.00	24.0
Obs	58:	1.000	4.00	4.00	4.00	8.00	26.0
Obs	59:	1.000	4.00	4.00	4.00	8.00	28.0
Obs	60:	1.000	4.00	4.00	4.00	8.00	30.0
Obs	61:	0.883	4.00	4.00	4.00	10.0	2.00
Obs	62:	0.976	4.00	4.00	4.00	10.0	4.00
Obs	63:	0.993	4.00	4.00	4.00	10.0	6.00
Obs	64:	0.998	4.00	4.00	4.00	10.0	8.00
Obs	65:	0.999	4.00	4.00	4.00	10.0	10.0
Obs	66:	0.999	4.00	4.00	4.00	10.0	12.0
Obs	67:	1.000	4.00	4.00	4.00	10.0	14.0
Obs	68:	1.000	4.00	4.00	4.00	10.0	16.0
Obs	69:	1.000	4.00	4.00	4.00	10.0	18.0
Obs	70:	1.000	4.00	4.00	4.00	10.0	20.0
Obs	71:	1.000	4.00	4.00	4.00	10.0	22.0

Enter delta0, delta1, siglev, xbar, ybar, varx, vary, m, n :
0,4,.1,30,11,6.25,6.25,4(2)16,4(2)16

Variable:	PowerOfTe	delta1	varx	vary	m	n
Obs 1:	0.793	4.00	6.25	6.25	4.00	4.00
Obs 2:	0.856	4.00	6.25	6.25	4.00	6.00
Obs 3:	0.889	4.00	6.25	6.25	4.00	8.00
Obs 4:	0.908	4.00	6.25	6.25	4.00	10.0
Obs 5:	0.920	4.00	6.25	6.25	4.00	12.0
Obs 6:	0.929	4.00	6.25	6.25	4.00	14.0
Obs 7:	0.935	4.00	6.25	6.25	4.00	16.0
Obs 8:	0.856	4.00	6.25	6.25	6.00	4.00
Obs 9:	0.915	4.00	6.25	6.25	6.00	6.00
Obs 10:	0.942	4.00	6.25	6.25	6.00	8.00
Obs 11:	0.958	4.00	6.25	6.25	6.00	10.0
Obs 12:	0.967	4.00	6.25	6.25	6.00	12.0
Obs 13:	0.973	4.00	6.25	6.25	6.00	14.0
Obs 14:	0.977	4.00	6.25	6.25	6.00	16.0
Obs 15:	0.889	4.00	6.25	6.25	8.00	4.00
Obs 16:	0.942	4.00	6.25	6.25	8.00	6.00
Obs 17:	0.966	4.00	6.25	6.25	8.00	8.00
Obs 18:	0.977	4.00	6.25	6.25	8.00	10.0
Obs 19:	0.984	4.00	6.25	6.25	8.00	12.0
Obs 20:	0.988	4.00	6.25	6.25	8.00	14.0
Obs 21:	0.990	4.00	6.25	6.25	8.00	16.0
Obs 22:	0.908	4.00	6.25	6.25	10.0	4.00
Obs 23:	0.958	4.00	6.25	6.25	10.0	6.00
Obs 24:	0.977	4.00	6.25	6.25	10.0	8.00
Obs 25:	0.987	4.00	6.25	6.25	10.0	10.0
Obs 26:	0.991	4.00	6.25	6.25	10.0	12.0
Obs 27:	0.994	4.00	6.25	6.25	10.0	14.0
Obs 28:	0.996	4.00	6.25	6.25	10.0	16.0
Obs 29:	0.920	4.00	6.25	6.25	12.0	4.00
Obs 30:	0.967	4.00	6.25	6.25	12.0	6.00
Obs 31:	0.984	4.00	6.25	6.25	12.0	8.00
Obs 32:	0.991	4.00	6.25	6.25	12.0	10.0
Obs 33:	0.995	4.00	6.25	6.25	12.0	12.0
Obs 34:	0.997	4.00	6.25	6.25	12.0	14.0
Obs 35:	0.998	4.00	6.25	6.25	12.0	16.0
Obs 36:	0.929	4.00	6.25	6.25	14.0	4.00
Obs 37:	0.973	4.00	6.25	6.25	14.0	6.00
Obs 38:	0.988	4.00	6.25	6.25	14.0	8.00
Obs 39:	0.994	4.00	6.25	6.25	14.0	10.0
Obs 40:	0.997	4.00	6.25	6.25	14.0	12.0
Obs 41:	0.998	4.00	6.25	6.25	14.0	14.0
Obs 42:	0.999	4.00	6.25	6.25	14.0	16.0
Obs 43:	0.935	4.00	6.25	6.25	16.0	4.00
Obs 44:	0.977	4.00	6.25	6.25	16.0	6.00
Obs 45:	0.990	4.00	6.25	6.25	16.0	8.00
Obs 46:	0.996	4.00	6.25	6.25	16.0	10.0
47:	0.998	4.00	6.25	6.25	16.0	12.0
Obs 48:	0.999	4.00	6.25	6.25	16.0	14.0
Obs [illegible]	0.999	4.00	6.25	6.25	16.0	16.0

```
Enter delta0, delta1, siglev, xbar, ybar, varx, vary, m, n :
0,4,.1,30,11,9,9,4(2)10,4(2)10
```

Variable:		PowerOfTe	delta1	varx	vary	m	n
Obs	1:	0.681	4.00	9.00	9.00	4.00	4.00
Obs	2:	0.750	4.00	9.00	9.00	4.00	6.00
Obs	3:	0.789	4.00	9.00	9.00	4.00	8.00
Obs	4:	0.814	4.00	9.00	9.00	4.00	10.0
Obs	5:	0.750	4.00	9.00	9.00	6.00	4.00
Obs	6:	0.824	4.00	9.00	9.00	6.00	6.00
Obs	7:	0.864	4.00	9.00	9.00	6.00	8.00
Obs	8:	0.889	4.00	9.00	9.00	6.00	10.0
Obs	9:	0.789	4.00	9.00	9.00	8.00	4.00
Obs	10:	0.864	4.00	9.00	9.00	8.00	6.00
Obs	11:	0.904	4.00	9.00	9.00	8.00	8.00
Obs	12:	0.927	4.00	9.00	9.00	8.00	10.0
Obs	13:	0.814	4.00	9.00	9.00	10.0	4.00
Obs	14:	0.889	4.00	9.00	9.00	10.0	6.00
Obs	15:	0.927	4.00	9.00	9.00	10.0	8.00
Obs	16:	0.948	4.00	9.00	9.00	10.0	10.0

Bibliography

1. Allen, Thomas B. War Games. New York: McGraw-Hill Book Company, 1987.

2. Barnes, Alfred T. and others. The 1985 Satellite Directory. Bethesda, MD: Phillips Publishing Inc., 1985.

3. Bate, Roger R. and others. Fundamentals of Astrodynamics. New York: Dover Publications, Inc., 1971.

4. Bonder, Seth. "An Overview of Land Battle Modeling in the US," Proceedings 13th U.S. Army Operations Research Symposium. 73-88. November 1974.

5. Christensen, Bruce P. A New Approach to the Measurement of Educational Outcomes for Institutions of Higher Learning. PhD dissertation. The University of Utah, Salt Lake City UT, 1984.

6. Close, Wayne C. and others. The Falklands War. Northbrook, IL: Close Simulations, 1982.

7. Department of the Army. Inventory of TRADOC Models. Fort Leavenworth KS, January 1988.

8. Devore, Jay L. Probability and Statistics for Engineering and the Sciences. Monterey, CA: Brooks/Cole Publishing Company, 1987.

9. Dupuy, Col. T. N. "Criticisms of Combat Models Cite Unreliability of Results," Army: 16-18 (March 1985).

10. Ehrhart, Lt Col Robert C., Project Warrior Coordinator. Personal Correspondence. Department of the Air Force, XOXID, Washington, D.C., 1 December 1985.

11. Farrell, Robert L. and others. "Capturing Expertise: Some Approaches to Modeling Command Decisionmaking in Combat Analysis," IEEE Transactions On Systems, Man, and Cybernetics, SMC-16: 766-772 (November/December 1986).

12. Ganley, Gladys D. and Oswald H. Ganley. Unexpected War in the Information Age. Communications and Information in the Falklands Conflict. Cambridge, Massachusetts: Harvard University Center for Information Policy Research, 1984.

13. General Accounting Office. Models, Data, and War: A Critique of the Foundation for Defense Analyses. Report Series PAD-80-21. Washington: Government Printing Office, 12 March 1980.

14. Hartman, James K. Unpublished Lecture Notes in High Resolution Combat Modeling. Unitied States Naval Postgraduate School, Monterey CA, 1985.

15. Hughes, Wayne P., Jr. and others. Military Modeling, The Military Operations Research Society, Alexandria, VA: 1984.

16. Kachigan, Sam Kash. Statistical Analysis. New York: Radius Press, 1986.

17. Kapper, Francis B. "Wargaming," Defense: 14-21 (May 1981).

18. Law, Averill M. and W. David Kelton. Simulation Modeling and Analysis. New York: McGraw-Hill Book Company, 1982.

19. Lenth, Russell V. PowerPack Version 2.2. MSDos Statistical Software package and User's Guide. Iowa City, Iowa, 1987.

20. McElroy, John H. and others. Space Science and Applications Progress and Potential. New York: IEEE Press, 1986.

21. McFarren, Major Mike, Modeler for Armstrong Medical Research Laboratory. "Modeling of Human Cognitive Processes." Address to AFIT students. Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 30 August 1988.

22. Meiers, Lt Col John. "Center for Aerospace Analysis Progress Report." United States Space Command, Peterson AFB CO, March 1988.

23. Morgan, Captain Gary C. and others. FEBA. Northbrook, IL: Close Simulations, 1982.

24. Payne, Wilbur B. "Ground Battle Models" found in Military Modeling, The Military Operations Research Society, Alexandria, VA: 1984.

25. Peck, Capt Allen G. Validation of the Runway Attack Methodology of the Naval War College Air Model (NWCAM). MS thesis, AFIT/GST/OS/85M-11. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1985 (AD-B092398).

26. Porter, Richard W., Deputy Director U.S. Army TRADOC Analysis Command and co-author of the model Vector-In-Commander. Telephone interview. White Sands MIssile Range NM, 5 May 1988.

27. Prados, John. Pentagon Games Wargames and the American Military. New York: Harper & Row, Publishers, 1987.

28. Reynolds, Daniel F. Class Handout distributed in Math 597, Statistics for Space Operations. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, January 1988.

29. Reyen, Major Dan. Instructor of Operations Research, School of Engineering. Personal Interview. Air Force Institute of Technology(AU), Wright-Patterson AFB OH, July 1988.

30. Rowland, D. "The Use of Historical Data in The Assessment of Combat Degradation," Journal of Operational Research Society, 38: 149-162, (February 1987).

31. Shannon, Robert E. "Simulation: A Survey with Research Suggestions," AIIE Transactions: 289-301 (September 1975).

32. Specht, R. D. "The Nature of Models" found in Systems Analysis and Policy Planning: Applications in Defense. Edited by E. S. Quade and W. I. Boucher. Contract No. F44620-73-C-0011. Santa Monica, CA: RAND Corporation, 1968.

33. SPI. The Campaign for North Africa The Desert War 1940-43. New York: Simulations Publications, 1979.

34. Sugarman, Robert and Paul Wallich. "The limits to Simulation" IEEE Spectrum, 20, No.4 36-41, (April 1983).

35. Thurman, General M. R., CG TRADOC USA. Keynote Address to 27th AORS Symposium, Ft Lee VA, 12 October 1988.

36. Wand, K. and R. J. T. Wilson. "Matador: An Analytic Model of a Stochastic Tank Duel," Journal of The Operational Research Society, 38, No. 6, 545-551, 1987.

37. Weiner, M. G. "Gaming" found in Systems Analysis and Policy Planning: Applications in Defense. Edited by E. S. Quade and W. I. Boucher. Contract No. F44620-73-C-0011. Santa Monica, CA: RAND Corporation, 1968.

Vita

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TIM G. CORDNER, CAPTAIN USAF

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The purpose of this study was to examine the impact of satellite information on combat modeling. Modeling validity may be enhanced when greater detail is included in the model. The degree to which the model results may change by providing satellite information to, or deleting it from, the combatants in the model comprised the focus of this study.

A war game, titled The Falklands War was used as the combat model. This game provided a series of results wherein the British forces were supplied satellite information. Additional play of the game removed this satellite information from the British forces and provided it to the Argentine forces. These two styles of play resulted in statistical data for analysis of the impact satellite information has on the results of this model.

The statistical analysis conducted on this model provided insufficient evidence suggesting the impact of satellite information on the model. Player variability and lack of sufficient data were determined to be the primary reasons. However, from the data collected, little is observed which indicates playing satellite information in a board game, similarly to what has been done here, will produce the evidence needed to justify modifications to more extensive and complex models.

Keywords: -Satellite data, Games, Statistical analysis, Theses, Satellite communications. (SDW)